VOLUME 9 • NUMBER 10 • OCTOBER, 1938

METALS and ALLOYS

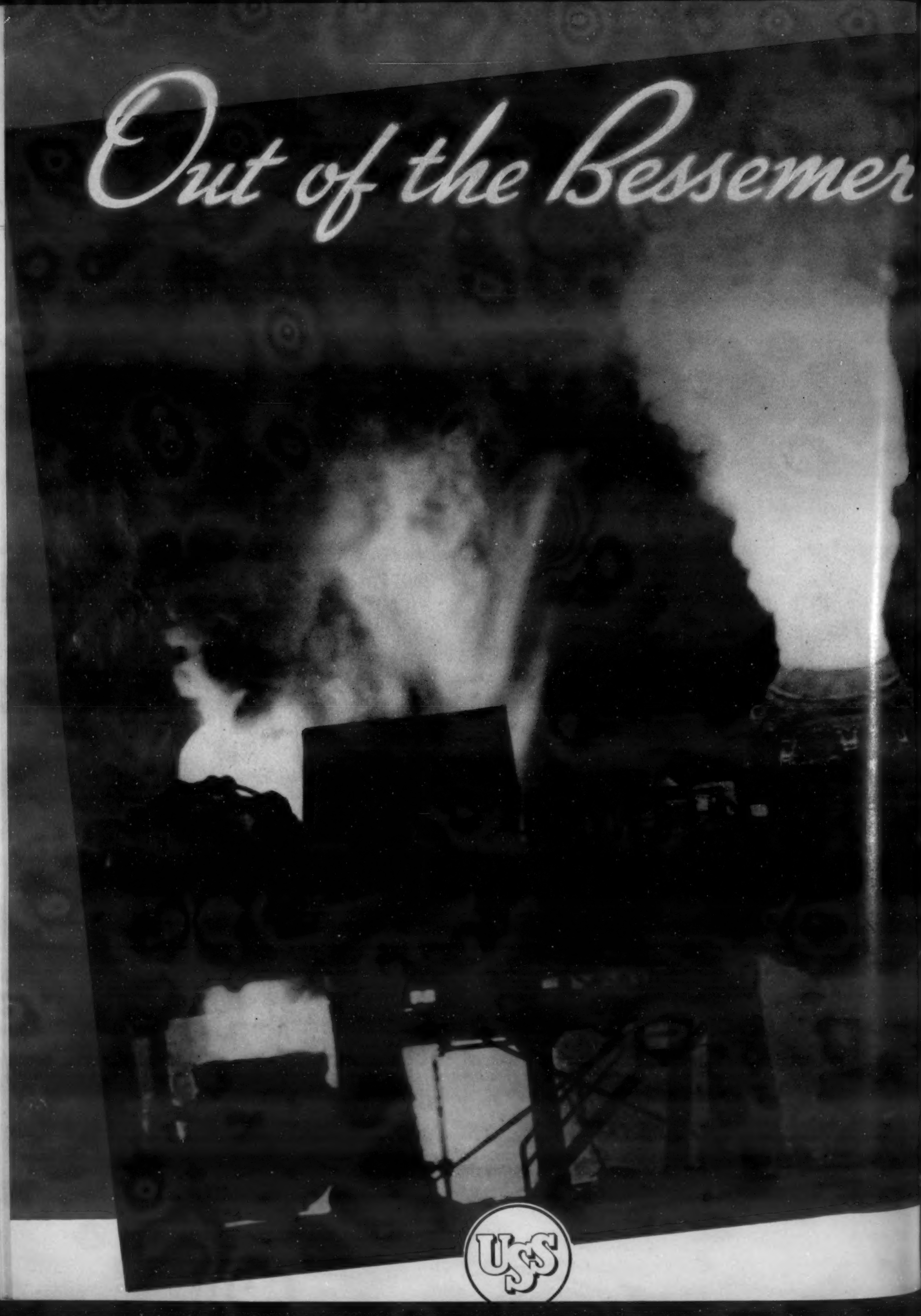
The Magazine of Metallurgical Engineering

PRODUCTION • FABRICATION • TREATMENT • APPLICATION

Published Monthly by Reinhold Publishing Corporation, East Stroudsburg, Pa., U.S.A. Ralph Reinhold, President and Treasurer; H. Burton Lowe, Vice President and Secretary; Philip H. Hubbard, Vice President; Francis M. Turner, Vice President. Executive and Editorial Offices, 330 West 42nd Street, New York. Price 40 cents a copy. Annual Subscription: U. S., Possessions and Canada, $2.00. All Other Countries, $3.00. (Remit by New York Draft). Entered as second class matter June 12, 1934, at the Post Office at East Stroudsburg, Pa., under the Act of March 3, 1879.

ARTICLES

METALLURGICAL ABSTRACTS


Out of the Bessemer
USS

THE PRESENT STATUS OF THE

Low Alloy High Strength Steels

—A SURVEY

by Edwin F. Cone

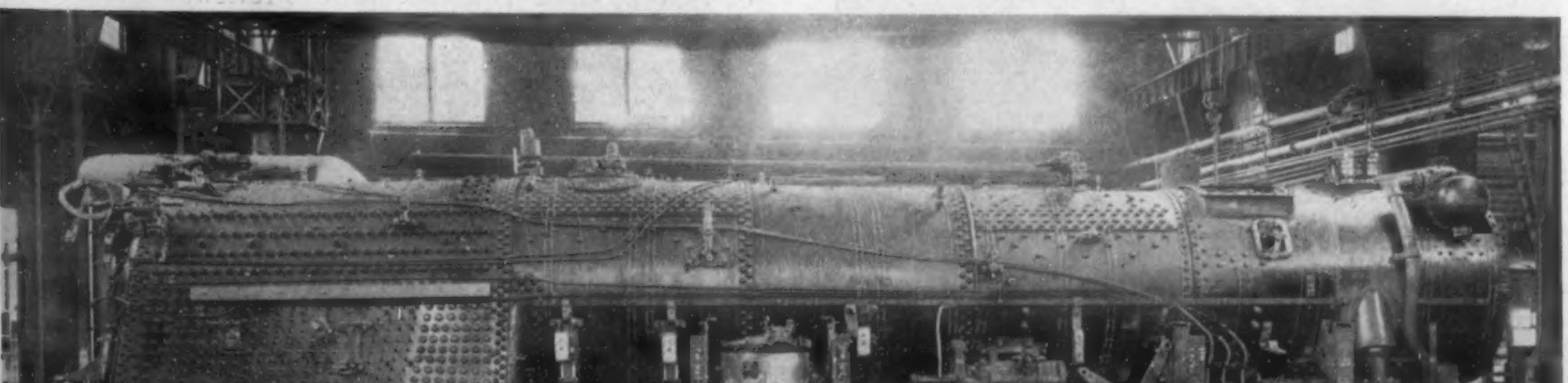
ABOUT THREE OR FOUR YEARS ago there appeared on the metallurgical horizon the first indication of a group of steels which today play a major role—the low-alloy high strength (or high elastic) structural steels. The steel which may be regarded as the first of these modern ones is "Cromansil," developed about 9 yrs. ago by the Electro Metallurgical Co. of New York. To be sure, before this there existed the low-alloy nickel steels and one or two others. Soon after this, in rather rapid succession, structural engineers were offered numerous other brands of varying composition until early in 1936 the total approximated 29 steels under special trade designations. In the last year or two at least three other steels of this general class have been developed by metallurgical engineers.

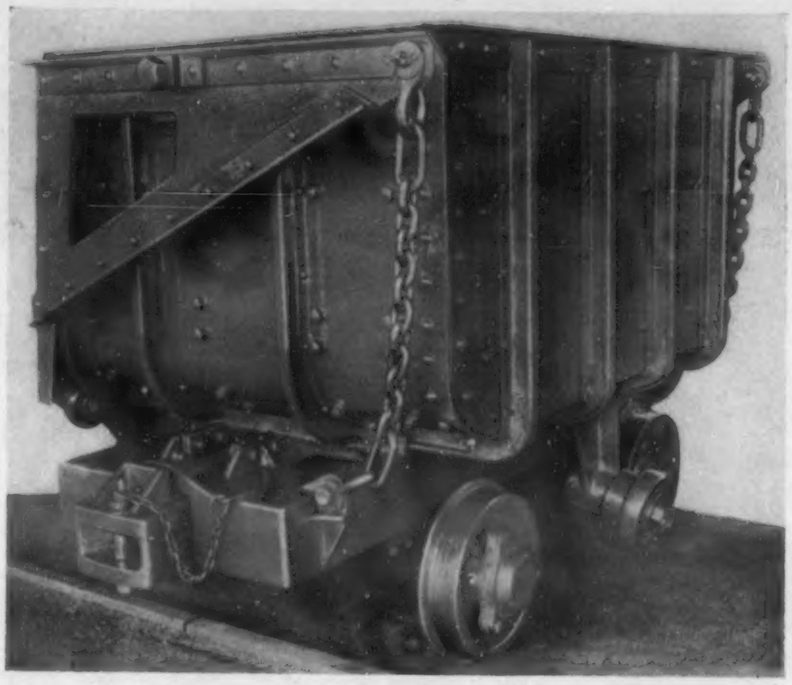
Many claims have been made, and are still made, for these steels, some rather fantastical and some essentially sound. After a period of about 3 yrs. it has seemed reasonable to review the present status of the class as a whole, particularly with reference to the uses to which they are being put. It is of course true that a sufficient time has not elapsed to check up on all the claims that are made, but it is a fact that these steels—developed primarily to be used where weight can be reduced without sacrifice of strength—have gained in favor with designers of structures and other products. Large tonnages, usually in the as-rolled condition, are now being used.

It is the aim of this article, or review, to survey the field of applications of most of the steels, demonstrated by illustrations; to present the present status as to composition or any material changes in the original steels; and to describe the newer ones. It is based on a questionnaire sent to the producers and sponsors of the different steels.

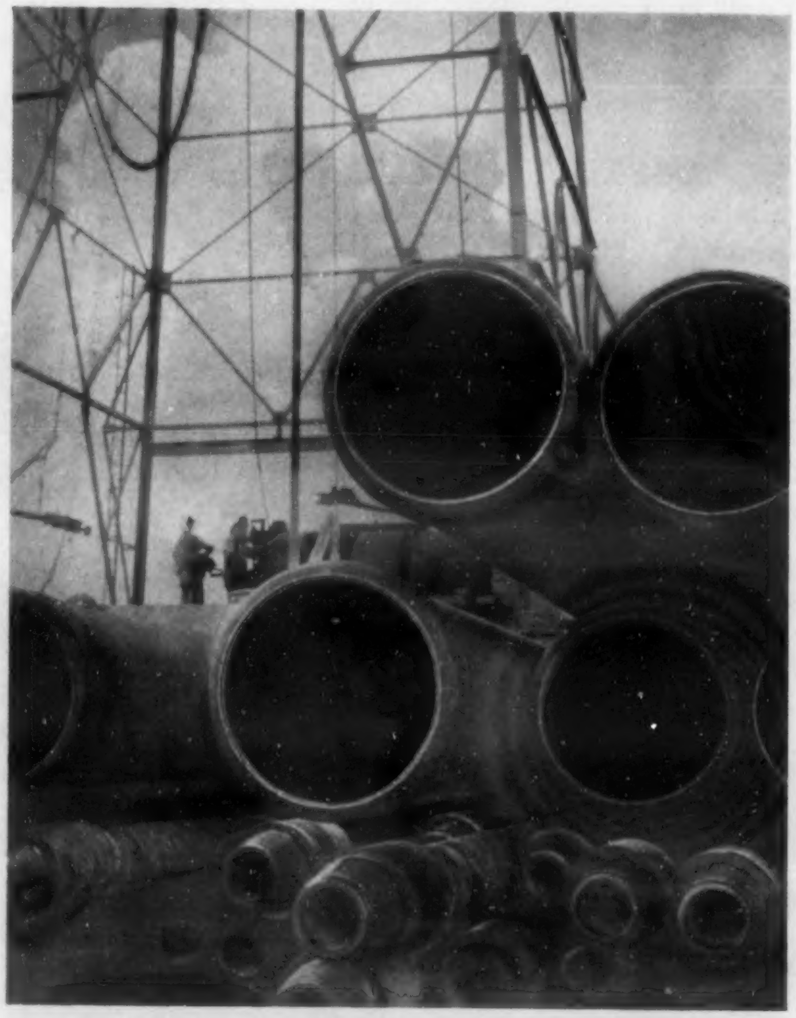
In the literature of recent date, there have been several discussions of the low-alloy, high elastic steels. Gillett[1]

Nickel Steel (2% Ni) Boiler Shell for Canadian Pacific Locomotive (Courtesy: International Nickel Co.)





Granby Mine Car (3½% Ni) for INCO Mines, Built by Canadian Car & Foundry Co. Steelplate furnished by Dominion Foundries & Steel Co., Ltd. (Courtesy: International Nickel Co.)



Oil Well Casings are Made of Mn-Mo Steel.

Largest Gasoline Tank Trailer Train, Constructed of "U. S. S. Cor-Ten." (Courtesy: United States Steel Corp.)

in a paper before the A.I.M.E. in February, 1936; Epstein, Nead and Halley[2] in another contribution at the same annual meeting; and Cone[3] at the annual spring committee meetings of the A.S.T.M. in 1936 discussed various metallurgical and other properties of these steels. An extended abstract[4] of these three papers was published in METALS AND ALLOYS—for the busy reader. In the paper by Cone[3] in which were discussed in some detail the properties of, and claims for, these steels, a table (Table XI) was presented which listed 15 "steel company" steels and about 14 others including the S.A.E. nickel steels, the medium manganese and the silicon structural steels. Selecting from this list those which may be designated as the more modern ones, we have the following in existence in early 1936:

Trade Name	Company
"Cromansil"	Electro Metallurgical Co.
"Manganese-Vanadium"	Vanadium Corp. of America
"Carbon-Molybdenum"	Climax Molybdenum Co.
"Manganese-Molybdenum"	Climax Molybdenum Co.
"Cor-Ten"	United States Steel Corp.
"Man-Ten"	United States Steel Corp.
"Sil-Ten"	United States Steel Corp.
"Yoloy"	Youngstown Sheet & Tube Co.
"R.D.S. 1"	Republic Steel Corp.
"R.D.S. 1A"	Republic Steel Corp.
"Hi-steel"	Inland Steel Co.
"HT-50"	American Rolling Mill Co.
"AW 70-90A"	Alan Wood Steel Co.
"AW 70-90B"	Alan Wood Steel Co.
"Jal-Ten"	Jones & Laughlin Steel Corp.
"Granite City HS 1"	Granite City Steel Co.
"Granite City HS 2"	Granite City Steel Co.
"Centralloy"	Central Iron & Steel Co.
"Konik"	Continental Steel Corp.

Thus there were 15 "company steels" and four steels sponsored by alloy companies—these in addition to the nickel and other steels. Since then there have not only been some changes and additions, but also no little experience in their application and in a knowledge of their properties.

Taking these steels in the order listed in the foregoing paragraph, attention is now called to a few of the outstanding changes in composition, physical properties and so on. Instead of discussing them in detail a table (Table 1) is compiled showing the present composition and also one (Table 2) showing the physical properties, as reported. These can be compared with the data from other papers—for convenience the table (Table XI) of compositions as of 1936 by Cone[3] is repeated in this review.

The Early Steels

THERE is a group of low alloy high strength steels which have been in existence, some of them for many years. Included in these are the S. A. E. Ni, Ni-Cr and Ni-Mo steels, medium Mn, silicon structural, Cr-V, Cromansil, Mn-V, C-Mo, and Mn-Mo steels. This group is contrasted with the so-called "company steels." A brief discussion of the present status of these steels follows:

The Nickel Steels—International Nickel Co.

For many years the low alloy nickel steels have been used in many applications—in the as-rolled as well as after heat treatment. They are still widely used today, because of their many excellent properties, as plates, shapes, forgings and so on.

The steels which are very briefly touched on in this re-

view are the so-called non-proprietary steels as distinguished from the steels promoted by steel companies. In several of the latter Ni is a predominant element—"Republic Double Strength," "Yoloy" and others. The non-proprietary steels are principally some of the S. A. E. group. These were discussed in some detail in the paper by Cone.[3] Since then there have been a few minor changes in composition and in physical properties. Compare Table 1 with Table XI reproduced from the A.S.T.M. paper already cited. For representative physical properties see Table 2.

In applications in structural work these steels have found and are still finding industrial applications. In the as-rolled condition they are found in bridge construction, in boilers particularly for locomotives, in skip hoists and cages for mines, in mine cars and so on. Space does not permit discussion of other details in properties and applications.

"Cromansil" — Electro Metallurgical Co. and Lukens Steel Co.

"Cromansil"—a Cr-Mn-Si low alloy steel—as before stated, was introduced some 8 or 9 yrs. ago by the Electro Metallurgical Co. of New York. It is regarded by some as a company steel because of the work done on it and for it by the Lukens Steel Co., Coatesville, Pa. From this company the following facts have been received:

This steel is now offered in two grades—A and B as contrasted with only one when introduced. The two grades differ as to composition only in the carbon content —0.17 per cent max. for Grade A and 0.25 per cent max. for Grade B. When first introduced the Mn range was 1.00 to 1.40 per cent—it is now, for both grades, 1.05 to 1.40 per cent, a slight alteration. Si range remains unchanged at 0.60 to 0.90 per cent, in both grades. The Cr is now 0.30 to 0.60 per cent as contrasted with 0.40 to 0.60 per cent earlier. Cu, which was formerly optional, is not now mentioned. See Table 1. P and S are 0.035 and 0.04 per cent max. respectively.

The physical properties, based on experience to date, are:

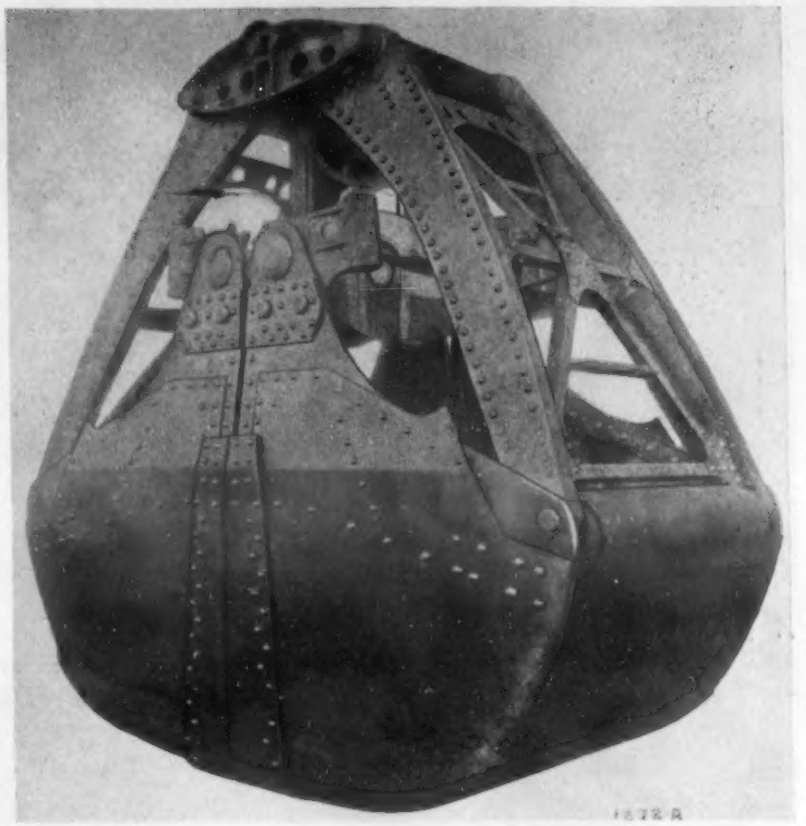
	Grade A	Grade B
Tensile strength	75,000 to 90,000 lbs.	85,000 to 100,000 lbs.
Yield point	0.6 of T.S.	0.55 of T. S.
Elongation	1,600,000 lbs.	1,600,000 lbs.
	T. S.	T. S.
Brinell	140 to 180 (as rolled)	160 to 200 (as rolled)
Brinell	130 to 170 (stress relieved)	150 to 190 (stress relieved)

No data are furnished as to other properties nor any information as to applications though it is generally understood that this steel has been and is being used in many applications, both welded and otherwise in structural work.

Manganese-Vanadium— Vanadium Corp. of America

Considerable work has been done on this grade of low alloy steel. It is now offered for plates, shapes and flats, in three grades, A, B, and C. In general the carbon ranges from 0.18 to 0.22 per cent max., the Mn from 1.35 to 1.55 per cent max., the Si from 0.15 to 0.30 per cent and the V from 0.08 to 0.14 per cent. (Table 1). For comparison with that announced earlier, see Table XI from paper by Cone.[3] The changes are not radical.

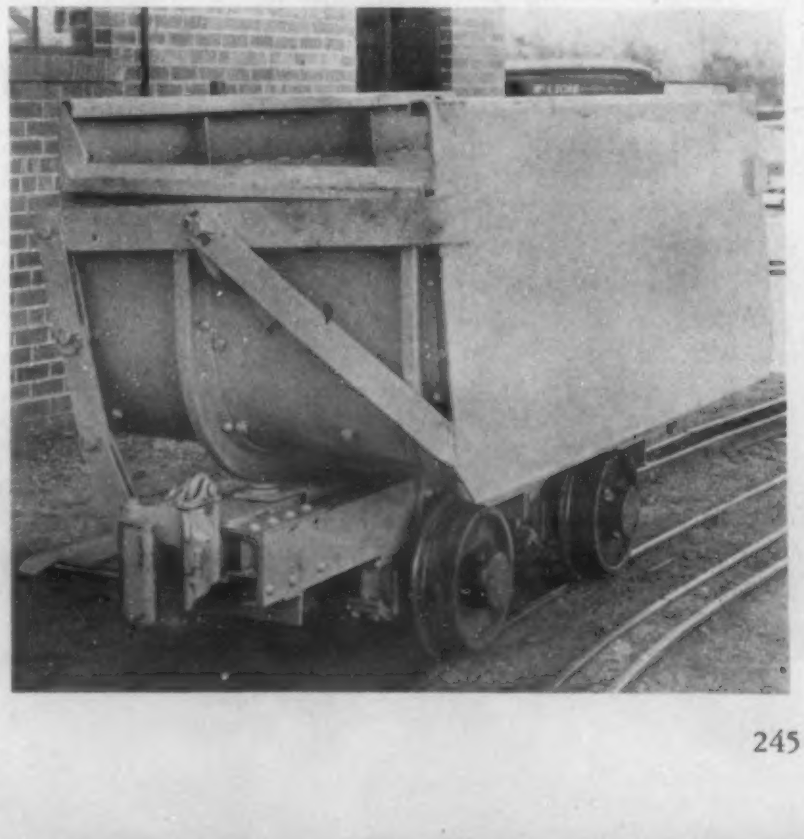
As to physical properties the three grades vary in tensile strength (as-rolled) from 70,000 to 105,000 lbs. per sq. in. min., with the yield point from 42,000 to 60,000 lbs. per sq. in. min., depending on the composition and thick-



Constructed of "U. S. S. Cor-Ten," This Giant Shovel Has Been Increased in Capacity 20 Per Cent. It weighs 17,000 lbs., picks up 24,000 lbs. of coal at one bite. It has a weight capacity ratio of 1 to 1.4 as compared to 1 to 1 best obtainable by conventional steel construction.

Coal Unloading Bucket of "U. S. S. Man-Ten" Combines Light Weight, Increased Capacity and Abrasion Resistance (Courtesy: United States Steel Corp.)

A 2½ Ton Mine Car of "Yoloy" Steel. Net reduction in weight is 392 lbs. (Courtesy: Youngstown Sheet & Tube Co.)



A 3200-Gal. Tank of "Yoloy" Steel. It weighs 4800 lbs., the saving being 1600 lbs. over ordinary structural steel. (Courtesy: Youngstown Sheet & Tube Co.)

ness. For example, the 42,000 min. yield point refers to the steel of lowest C and Mn content when thicknesses are above 2 in. The elongation in 2 in. averages from 22 to 28 per cent min., also depending on thickness. These values are in most cases higher than those originally reported (see paper by Cone[3]). See Table 2.

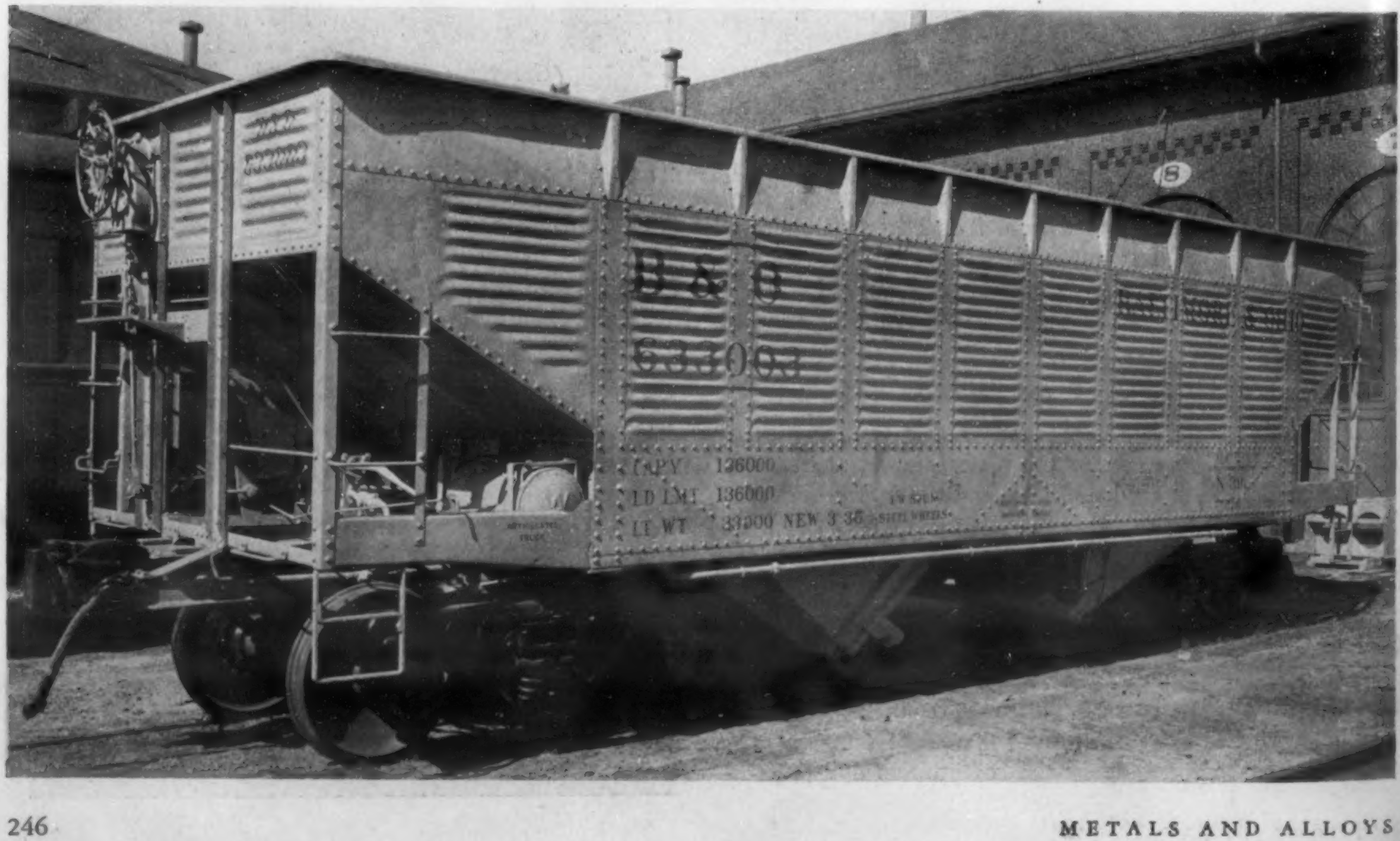
Mn-V steel for boilers and other pressure vessels is also offered and used. In this the C is 0.18 per cent max., the Mn 1.35 per cent max., the Si 0.15 to 0.30 per cent and the V 0.08 to 0.14 per cent with maximum limits set for incidental impurities such as Ni, Cr, Cu and Mo. The tensile strength (as-rolled) varies from 70,000 to 85,000 lbs. per sq. in. with the yield point from 42,000 to 50,000 lbs. per sq. in. min., depending on thickness. Elongation in 2 in. is about 28 per cent.

For bars and rivets two grades of Mn-V exist (A and B) with the C at 0.18 per cent max. for both and the Mn 1.35 and 1.45 per cent max. respectively; the Si and V are the same as in the other steels above.

Large quantities of Mn-V steels are in use today, particularly in the super-structure of marine vessels, because of not only the high strength properties, but also the superior welding characteristics.

Cr-V steel, which is really S.A.E. 6120, has of course not been changed as to composition or otherwise since its inclusion in the paper by Cone.[3] This steel is being used in pressure vessels, welded or not, which are usually stress relieved, annealed or normalized.

A Hopper Car Built of "Republic Double Strength Steel." Capacity: Nominal 100,000 lbs.; revenue 136,000 lbs.; weight 33,000 lbs. Ratio light weight to revenue load, 1 to 4. (Courtesy: Republic Steel Corp.)



A Passenger Car Roof of "Republic Double Strength Steel" for the Pullman Standard Car Mfg. Co. (Courtesy: Republic Steel Corp.)

The Molybdenum Steels— Climax Molybdenum Co.

There are two types of low alloy Mo steels—the C-Mo and Mn-Mo,—three with S.A.E. X4130. Considerable work has been done on these steels and experience has been gained from actual installations.

C-Mo: The principal change in the composition from condition, with the C from 0.13 to 0.21 per cent, the yield that originally announced is in the Mo content which now stands at an average of 0.40 to 0.60 per cent in a representative grade. The Mn is 0.50 to 0.90 per cent and the Si is 0.15 to 0.30 per cent. C ranges from 0.13 to 0.25 per cent. (Table 1)

Physical properties vary depending largely on the C content and the thickness of the section. In the as-rolled

Car Bolster Made of "Inland Hi-Steel," Arc Welded. (Courtesy: Inland Steel Co.)

Cold Flanging "Inland Hi-Steel" (Courtesy: Inland Steel Co.)

point is reported at 42,000 to 57,000 lbs. per sq. in. and the tensile strength at 72,000 to 79,000 lbs. per sq. in. with the elongation in 8 in. at 27.0 and 20.0 per cent respectively. Many other values are obtainable depending on the composition. (Table 2)

This C-Mo steel has found extensive use in boilers and pressure vessels, particularly because of its good high temperature strength and welding qualities.

Mn-Mo: For steels in the as-rolled conditions, the C averages 0.15 to 0.30 per cent with the Mn at 1.20 to 1.75 per cent, the Si at 0.20 to 0.50 per cent and the Mo 0.20 to 0.50 per cent. (Table 1)

The physical properties of such steels, depending on the analysis and section, have a yield point of 50,000 to 80,000 lbs. per sq. in. with the tensile strength at 75,000 to 120,000 lbs. per sq. in. (as-rolled). (Table 2)

X4130: Another steel which may be regarded as falling into the type of steels here discussed is S.A.E. X4130, a Cr-Mo steel. Its composition and properties are listed in Tables 1 and 2. Considerable quantities are used as sheets in the as-rolled and normalized condition.

The Mn-Mo steels are found to be easy to handle in fabricating operations. They respond well to heat treatment, and have good depth hardening characteristics. Weld-

Truck for Spreading Hot Surfacing Materials Made of "Armco H. T.-50," 10 Gage. (Courtesy: American Rolling Mill Co.)

ing properties are found to compare favorably with those of carbon steel.

Generally the Mn-Mo steels are used where a high strength weldable steel is essential. Typical examples would include oilwell casing and drill pipe as well as installation where high temperature strength is desirable. Its use in oil field equipment is reported as expanding.

The Steel Company Steels

UNDER this designation there is here presented, briefly, some of the changes and experiences of the companies with their individual steels in the last two or three years.

"Cor-Ten", "Man-Ten" "Sil-Ten"—U. S. Steel Corp.

A few changes have been stipulated in the chemical composition of these steels. They consist mainly in a maximum for C, a change in Mn ranges and limits to the Si percentages—maximum and minimum instead of a range. Some alterations, based on experience, are also reported in physical properties—minimum values for yield point and tensile strength, new values for elongations, endurance limit and so on. Charpy impact values have been substituted for Izod and figures for coefficient of expansion per deg. F. (70 to 300 deg.) are included. (Tables 1 and 2)

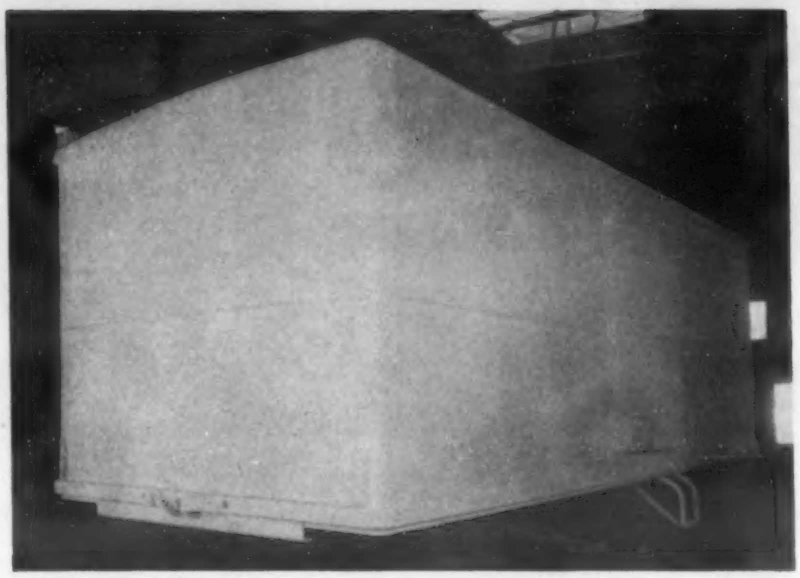
Based on experience to date (August, 1938) these steels are reported to be easily formed or pressed, hot or cold, to be readily welded (except Sil-Ten), to be capable of forging, punching or reaming and to be riveted under stipulated conditions. "Cor-Ten can be readily flame cut" but for Man-Ten and Sil-Ten flame cutting is possible if, in the greater thicknesses, they are pre-heated to approximately 500 deg. F. In milling and drilling, these steels are said to be more difficult than structural carbon steel—reduced speed should be used as well as a cooling agent; and more pressure is necessary.

Many have been the applications of these steels—the illustrations show some of them. A few include: Box cars 26.8 per cent lighter; gasoline tank semi-trailers carry 800 gals. more with 2.5 ton dead weight discarded and payload capacity increased over 30 per cent; streamlined street cars weighing 14 per cent less—and so on, all of Cor-Ten as compared with plain carbon steel; mine cars 10.69 per cent lighter and carrying 17 per cent more pay load; stripping shovel capacity increased 66⅔ per cent with excavating costs lowered 40 per cent—made of Man-Ten in comparison with plain carbon steel; approximately 70,000 tons, or 35 per cent of the steel in the San Francisco-Oakland Bay Bridge, of Sil-Ten.

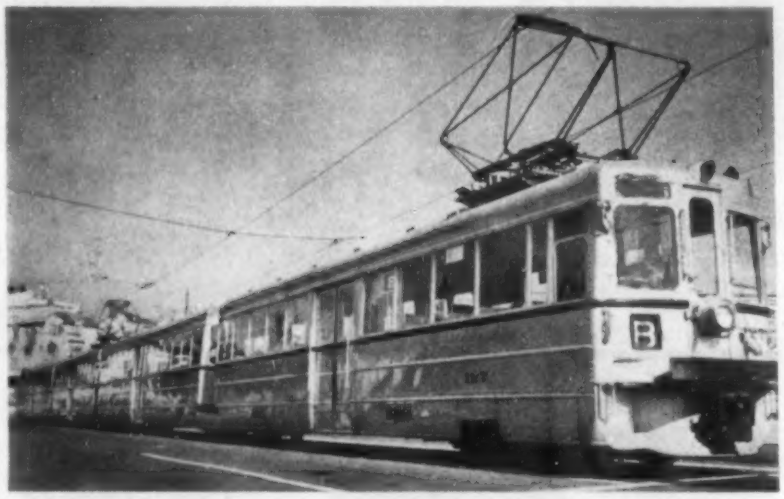
One of the most recent applications of Cor-Ten on a large scale is in the passenger cars of the new stream-lined Twentieth Century Limited of the New York Central and the Broadway Limited of the Pennsylvania.

"Yoloy"—Youngstown Sheet and Tube Co.

Some changes are reported in the chemical composition of Yoloy, the low-alloy high strength steel of the Youngstown Sheet & Tube Co. The carbon range has been expanded to 0.05 to 0.25 per cent as against 0.08 to 0.22 per cent when first announced. Ranges have been stipulated for Mn and Si where none were reported before. The Mn is now 0.30 to 0.90 per cent and the Si 0.10 to 0.25 per

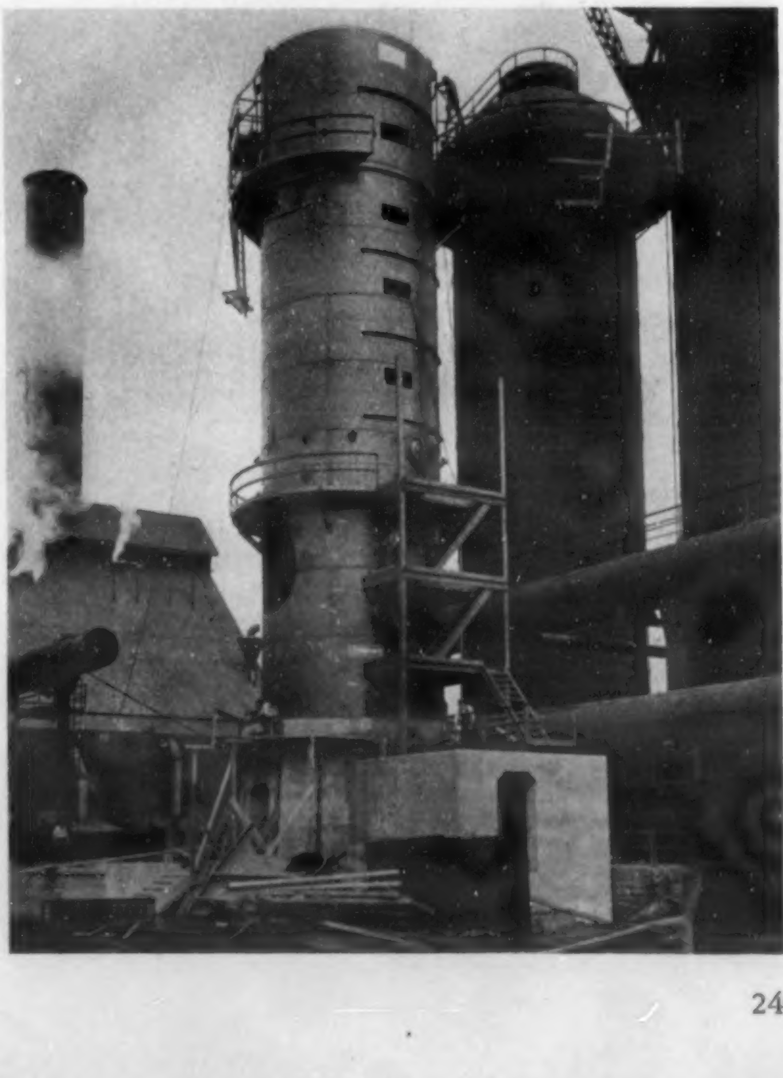


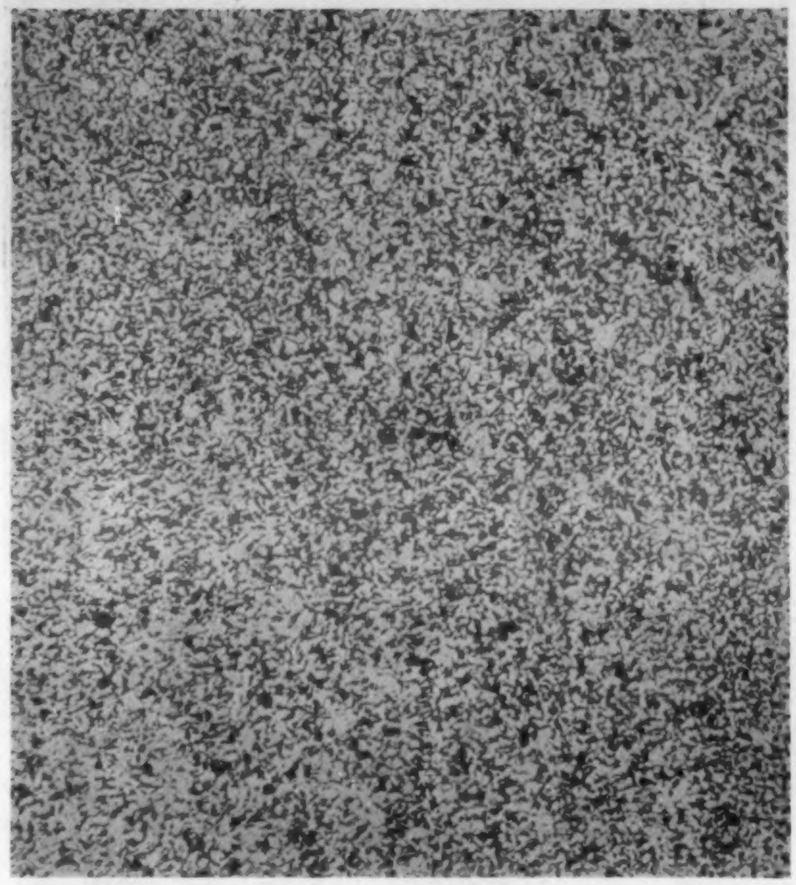
Exterior of Trailer Body, Made of 20 Gage "Armco H. T.-50" Cold Rolled Sheets (Courtesy: American Rolling Mill Co.)



Streamlined Cars Built for the Key System for Use on San Francisco-Oakland Bay Bridge, Built Substantially of "Mayari R Steel" (Courtesy: Bethlehem Steel Co.)

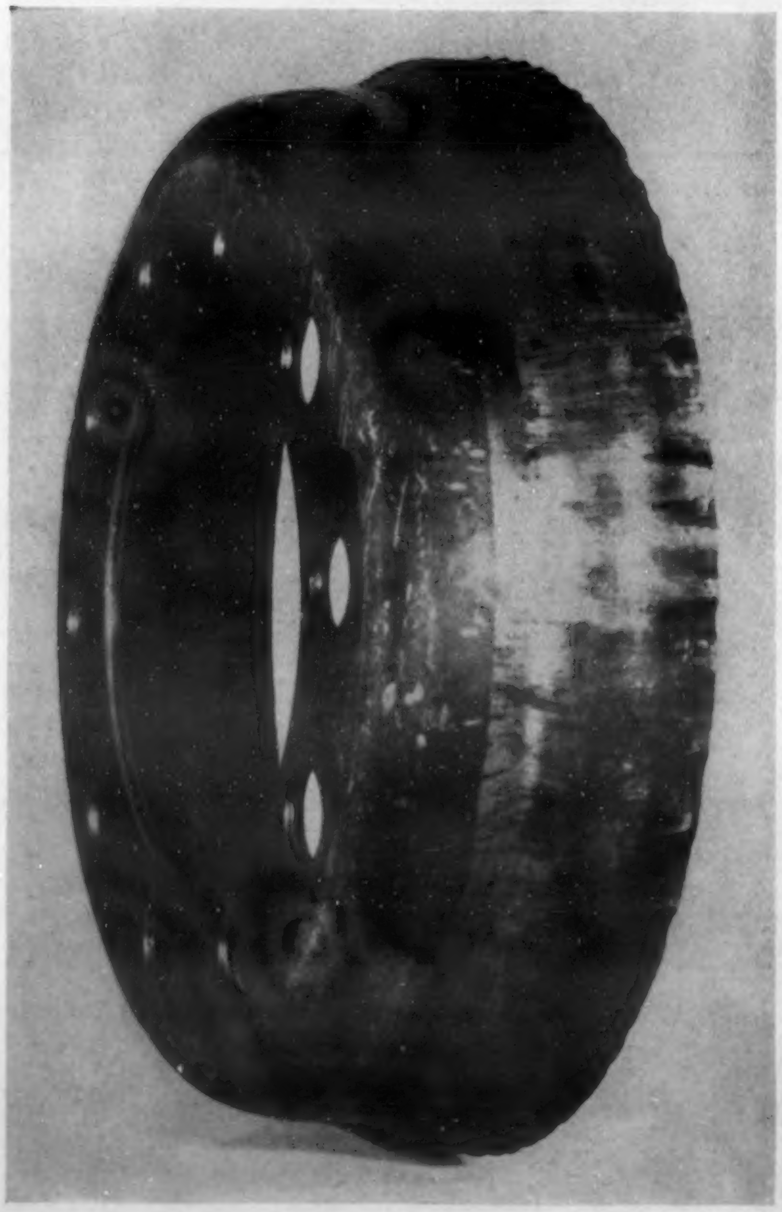
Gas Scrubbing Towers Made of "Mayari R Steel" (Courtesy: Bethlehem Steel Co.)





Structure of the New Low Alloy High Strength Steel of the Great Lakes Steel Corp. 100X. (Courtesy: Great Lakes Steel Corp.)

Truck Steel Wheel Cold Pressed from Great Lakes High Tensile Steel (Courtesy: Great Lakes Steel Corp.)



cent. Instead of a flat 1.00 per cent Cu the range is now 0.85 to 1.10 and instead of 2.00 per cent Ni, the range is now 1.50 to 2.00 per cent. (Table 1)

The physical properties in the as-rolled or hot-rolled condition are given in Table 2. In the paper by Cone[3] no data were then given.

The company states that the corrosion resistance of Yoloy is superior to that of ordinary copper steels and that it retains good impact strength at the low temperatures encountered in oil refining (de-waxing equipment). The steel is readily arc, resistance or gas welded. The high ductility grades can be drawn or stamped. Its use in industry has been growing.

Republic Double Strength, Grades 1 and 1A—Republic Steel Corporation

Emphasis is insisted on by the Republic Steel Corp. that the full name, instead of the abbreviation "RDS" formerly used, be employed. This is because another company has patent rights on another type of steel, named "RDS." The Republic steel is offered in two grades.

In composition some definite changes have been made since the announcement in 1935 and 1936.[3] There has been no change in the maximum limit on C in the two grades (Table 1), but a range in Mn is now stipulated, 0.50 to 1.00 per cent; the Cu and Ni remain the same but the molybdenum has been changed from a maximum of 0.20 per cent to a minimum of 0.10 per cent. Previously P was not stipulated but now in Grade No. 1 it is placed at a maximum of 0.10 per cent with 0.04 per cent maximum in Grade No. 2.

There have been some slight alterations in physical properties. In Grade No. 1 the yield point (as-rolled) approximates 55,000 lbs. per sq. in. min. (60,000 lbs. originally), the tensile strength is about 70,000 lbs. (75,000 lbs. originally) with the elongation in 2 in. unchanged at 25 per cent. In Grade No. 1A the yield point and tensile strength are unchanged at 70,000 and 90,000 lbs. per sq. in. respectively with the elongation in 2 in. now 15 per cent instead of 18 per cent.

The company claims that the combination of Cu, Mo and Ni in the percentages used gives high tensile, high yield-strength ratio, good ductility, low air-hardening characteristics and excellent corrosion resistance. Excellent forming qualities have been demonstrated and for welding it is excellent because of the low air-hardening characteristics. The atmospheric corrosion resistance is reported as having been "well proven"—"it has given trouble-free service since its development." Other properties are claimed and discussed in the new book—"Republic Alloy Steels."

"Inland Hi-Steel"—Inland Steel Co.

No changes in chemical composition have been made since Inland Hi-Steel was first announced. It is stated that the C is usually under 0.10 per cent, the Mn and P are usually near the mean of the range given in Table 1, the sulphur will be under 0.03 per cent maximum and the Si under 0.10 per cent maximum, while the Cu and Ni are reported to run near the mean of the range (Table 1).

The physical properties (Table 2) are now somewhat different than those originally promulgated, based of course

Nine Water-Cooled Gas Producer Shells Built of "Cor-Ten" Steel. "The high strength and corrosive resistance of this material justify its use where these properties are desirable. This steel is subject to little air-hardening in gas cutting and welding operations." (Courtesy: Wellman Engineering Co.)

on experience. The tensile strength (under $\frac{1}{8}$ in.) is now 75,000 lbs. per sq. in. with the yield point lower at 60,000 lbs.

This steel, says the company, is being fabricated by arc welding in practically all its applications. In most cases a plain carbon heavy coated rod is being used without stress relieving and in a few cases heavy coated rods with ferro-molybdenum in the coating are employed. Spot welding is also applicable.

As to atmospheric corrosion, tests have been run in 35 different types of environment with the following results: Under exposure to gases, this steel will show, according to the company, much greater corrosion resistance than plain C or Cu-bearing steels. Upon exposure to liquids not extremely corrosive, Inland Hi-Steel will show a marked superiority to the same two steels. Submerged in not extremely corrosive liquids, this steel shows some superiority but, when in very corrosive liquids, this steel reveals no superiority to the same two steels.

"Armco H. T.-50"— American Rolling Mill Co.

A few chemical changes are reported. The Mo is now 0.10 per cent min. and the Si is now 0.30 per cent min. against a trace originally. The Cu is put at a minimum of 0.35 per cent with the Ni set at 0.50 per cent min. with the phosphorus unchanged at 0.05 to 0.15 per cent. (Table 1)

No alterations are reported in the physical properties—they are practically the same as reported in 1936. (Table 2)

Experience has demonstrated, the company reports, unusually good welding properties for this steel, laboratory and service tests proving that welded parts have essentially the same yield and tensile strength as unwelded sheets and plates. Finished welds are said to be dense and tough, but also ductile as well.

"Comparative study shows" that under atmospheric conditions this steel has a corrosion resistance 4 to 6 times that of ordinary steel. No one element suffices, but it is claimed

An 82-Inch Steel Internal Gear of "Yoloy" Steel. This is one of an order of six. "High strength and weight reduction were required." (Courtesy: Wellman Engineering Co.)

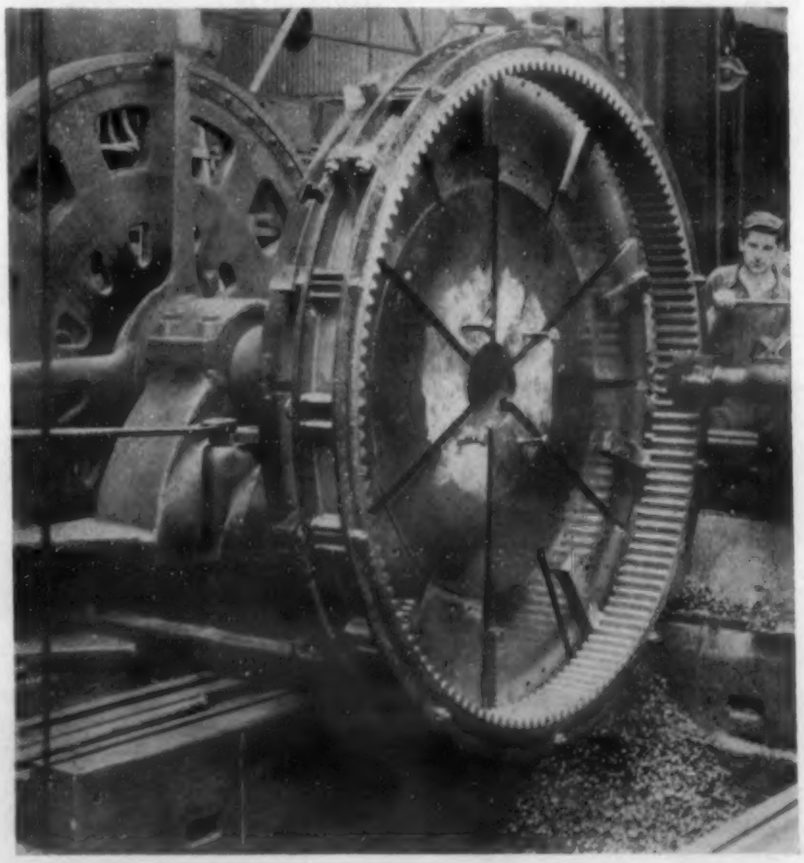


Table 1—Composition of Present-Day Low Alloy Steels (Per Cent)

Early Steels:	C	Mn	Si	Cu	Ni	Mo	P†	Other Elements
SAE 2115	0.10 to 0.20	0.30 to 0.60	....	....	1.25 to 1.75	....	....	....
2 to 2.5% Ni	0.20 max.	0.40 to 0.80	....	....	2.00 min.	....	....	....
2 to 2.5% Ni	0.35 max.	1.00 max.	....	....	2.00 min.	....	....	....
SAE 2300	0.45 max.	0.85 max.	....	....	3.00 to 4.00	....	....	(ASTM-A8-36T)
SAE 3130	0.25 to 0.35	0.50 to 0.80	....	....	1.00 to 1.50	....	....	0.45 to 0.75 Cr
SAE 3115	0.10 to 0.20	0.30 to 0.60	....	....	1.00 to 1.50	....	....	0.45 to 0.75 Cr
SAE 4630	0.25 to 0.35	0.50 to 0.80	....	....	1.65 to 2.00	0.20 to 0.30	....	....
SAE 4615	0.10 to 0.20	0.40 to 0.70	....	....	1.65 to 2.00	0.20 to 0.30	....	....
Medium Mn	0.20 to 0.25	1.00 to 1.75	....	....	....	....	....	....
Si Struc.	0.30 to 0.40	0.70 to 0.90	0.20 to 0.30	....	....	....	....	....
Cromansil A	0.17 max.	1.05 to 1.40	0.60 to 0.90	....	....	....	....	0.80 to 1.10 Cr, 0.15 min. V
Cromansil B	0.25 max.	1.05 to 1.40	0.60 to 0.90	....	....	....	....	0.30 to 0.60 Cr
Mn-V	0.18 to 0.22	1.35 to 1.55	0.15 to 0.30	....	....	....	....	0.30 to 0.60 Cr
Cr.-V	0.15 to 0.25	0.50 to 0.80	....	....	....	....	....	0.08 to 0.14 V
C-Mo	0.13 to 0.25	0.50 to 0.90	0.15 to 0.30	....	....	0.40 to 0.60	....	....
Mn-Mo	0.15 to 0.30	1.20 to 1.75	0.20 to 0.50	....	....	0.20 to 0.50	....	....
SAE X 4130	0.25 to 0.32	0.40 to 0.60	0.15 to 0.30	....	....	0.15 to 0.25	....	0.80 to 1.10 Cr
Company Steels:								
Cor-Ten	0.10 max.	0.10 to 0.50	0.50 to 1.00	0.30 to 0.50	....	....	0.10 to 0.20	0.50 to 1.50 Cr
Man-Ten	0.30 max.	1.25 to 1.70	0.30 max.	0.20 min.	....	....	0.04 max.	....
Sil-Ten	0.40 max.	0.60 min.	0.20 min.	0.20*	....	....	0.04 max.	....
Yoloy	0.05 to 0.25	0.30 to 0.90	0.10 to 0.25	0.85 to 1.10	1.50 to 2.00	....	....	....
R.D.S. 1	0.12 max.	0.50 to 1.00	....	0.50 to 1.50	0.50 to 1.00	0.10 min.	0.10 max.	....
R.D.S. 1A	0.30 max.	0.50 to 1.00	....	0.50 to 1.50	0.50 to 1.00	0.10 min.	0.04 max.	....
Hi-Steel	0.12 max.	0.50 to 0.70	0.30 max.	0.90 to 1.25	0.45 to 0.65	....	0.10 to 0.15	....
H.T.-50	0.12 max.	0.20 min.	0.10 max.	0.35 min.	0.50 min.	0.05 min.	0.05 to 0.15	....
A.W. 70-90A	Discontinued	for "A.W. Dyn-El"						
A.W. 70-90B	Discontinued	for "A.W. Dyn-El"						
Jal-Ten	0.35 max.	1.25 to 1.75	0.30 max.	0.40 max.	....	....	0.04 max.	....
Granite City HS1	No report							
Granite City HS2	No report							
Centralloy	No report							
Konik	....	....	....	0.10 to 0.30	0.30 to 0.50	....	....	0.07 to 0.30 Cr
New Steels:								
Mayari R	0.14 max.	0.50 to 1.00	0.05 to 0.50	0.50 to 0.70	0.25 to 0.75	....	0.04 to 0.12	0.20 to 1.00 Cr
A.W. Dyn-El	0.11 to 0.14	0.50 to 0.80	....	0.30 to 0.50	....	....	0.06 to 0.10	....
Great Lakes	Not yet announced							

* Optional. † P and S average 0.035 to 0.055 unless otherwise stated.

that the company's research workers have learned after years of extensive and careful study that P, Ni, Cu and the like, carefully proportioned, achieve remarkable results.

It is also pointed out that Armco H.T.-50 retains a ductility closely approaching ordinary steel, despite its high tensile strength. The steel has had wide acceptance. Some of the illustrations show a few applications.

"Jal-Ten"— Jones & Laughlin Steel Corp.

No change has been reported made in Jal-Ten since the data furnished in late 1935 and early 1936. These data will be found in the paper by Cone,[3] some of which are included in Tables 1 and 2.

A bulletin states that the welding of this steel is the same as plain low-C steel. It gives the joint strength of butt welded material at 82,850 lbs. per sq. in. (coated low carbon electrode) and at 86,020 lbs. per sq. in. (coated C-Mo electrode). The elongation free bend was 40.4 and 51.2 per cent respectively.

Three Steels Not Reported

Because of failure to reply to repeated solicitations, there

Table 2—Physical Properties of Present-Day Low Alloy Steels (As Rolled)

Early Steels:	Yield Pt.	T.S.	El. in 2 in.	Impact	Coef. of Exp.	End. Ratio	End. Limit
SAE 2115	45,000 [1]	65,000 [1]	28.0	....	....	...	.....
2 to 2.5% Ni	60% of T.S.	75,000 [1]	... [2]	....	....	...	.....
2 to 2.5% Ni [4]	65,000	100,000	30.0	....	....	...	.....
SAE 2300	50% of T.S. [14]	90 to 115,000	... [3]	....	....	...	.....
SAE 3130 [4]	65,000	95,000	25.0	....	....	...	.....
SAE 3115 [4]	53,000	74,000	30.0	....	....	...	.....
SAE 4630 [4]	76,000	103,000	23.0	....	....	...	.....
SAE 4615 [4]	60,000	82,000	28.0	....	....	...	.....
Medium Mn	Similar to Man-Ten						
Si Struc.	Similar to Sil-Ten						
Cromansil A	0.6 T.S.	75 to 90,000	... [5]	....	....	...	.....
Cromansil B	0.55 T.S.	85 to 100,000	... [5]	....	....	...	.....
Mn-V	42 to 60,000	70 to 105,000	22 to 28.0	....	....	...	.....
Cr-V							
C-Mo	42 to 57,000	72 to 79,000	27 & 20.6 [6]	....	....	...	.....
Mn-Mo	50 to 80,000	75 to 120,000	...	....	....	...	.....
SAE X 4130	70,000 [1]	90,000 [1]	20 to 10	....	....	...	.....
Steel company steels:							
Cor-Ten	50,000 [1]	70,000 [1]	22.0 [1]	40.0 [7]	6.7×10^{-6}	0.65	48,000 [13]
Man-Ten	50,000 [1]	80,000 [1]	20.0 [1]	30.0 [7]	6.5×10^{-6}	0.50	40,000 [13]
Sil-Ten	45,000 [1]	80 to 95,000	18.0 [1]	27.2 [7]	6.3×10^{-6}	0.47	38,000 [13]
Yoloy	53 to 69,000	70 to 95,000	21.0 to 27.0 [6]	45.0 [12]	....	...	.....
R.D.S. 1	55,000 [1]	70,000 [1]	25.0	....	....	...	.....
R.D.S. 1A	70,000 [1]	90,000 [1]	15.0	....	....	...	.....
Hi-Steel	55 to 60,000	75,000 [1]	20.0 [1]	65.0 [8,9]	....	...	49,000
H.T.-50	50,000 [1]	65 to 75,000	25.0 to 28.0	130.0 [9]	....	...	48,000
Jal-Ten	50,000 [1]	80,000 [1]	20.0 [1]	40.0 [9]	....	...	0.50 T.S. [1]
Granite City HS1	No report						
Granite City HS2	No report						
Centralloy	No report						
Konik	No report						
New steels:							
Mavari R	50,000 [1]	70,000 [1]	... [10]	75.0 [9]	....	...	50,000
A.W. Dyn-El	52 to 60,220	68 to 78,000	25.0 [1]	3550 [11]	....	...	45,000
Great Lakes	49 to 67,000	78 to 88,000	32.0 to 50.0	59 [7]	....	...	.....

[1] Min. [2] 1,600,000 ÷ T.S. 20% min. [3] 1,700,000 ÷ T.S. [4] Average results. [5] 1,600,000 ÷ T.S. [6] In 8 in. [7] Charpy. [8] 73 deg. F.; 48 at —40 deg. F. [9] Izod. [10] 1,500,000 ÷ T.S. pct. min. (8 in.). [11] Izod (Room Temperature) ft. lbs. per sq. in. [12] Room temp., 20 ft. lbs. at minus 100 deg. F. (high ductility grade). [13] Normalized. [14] 55,000 min.

are three steels, publicized in 1935-1936, concerning which no data are now available other than those then made public. These steels are:

"Granite City HS 1" }
"Granite City HS 2" } Granite City Steel Co.
"Centralloy"—Central Iron & Steel Co.
"Konik"—Continental Steel Corp.

The original data are found in the Table XI from the paper by Cone[3] and republished here.

The Three New Steels

IN the last year or so, three new low-alloy, high elastic steels have been introduced. They are as follows:

"Mayari R"—Bethlehem Steel Co.
"A. W. Dyn-El"—Alan Wood Steel Co.
A High Tensile Steel—Great Lakes Steel Corp.

"Mayari R"—Bethlehem Steel Co.

For many years the Bethlehem Steel Co. has produced the so-called Mayari alloy steels made from the Ni and Cr-bearing iron ores of Cuba (Mayari, Cuba). To meet the popular demand for a low cost steel for lighter equipment, a steel having increased strength and corrosion resistance, the company has perfected this steel. It is called "Mayari R," the R denoting rust resistance. Its chemical composition is reported as follows:

	Range	Typical		Range	Typical
Carbon	0.14 max.	0.08	Silicon	0.05 to 0.50	0.10
Manganese .	0.50 to 1.00	0.50	Chromium ..	0.20 to 1.00	0.25
Phosphorus .	0.04 to 0.12	0.099	Nickel	0.25 to 0.75	0.34
Sulphur ...	0.05 max.	0.035	Copper	0.50 to 0.70	0.55

The specifications for its physical properties in the as-rolled condition are:

Ultimate tensile strength	70,000 lbs. per sq. in. min.
Yield point	50,000 lbs. per sq. in. min.
Elong. in 8 in.	1,500,000 ÷ T. S. pct. min.
Izod impact	75 ft. lbs.
Endurance limit	50,000 lbs. per sq. in.

The Inner Ring in this Watch Case Vulcanizer is Highly Stressed in Service. "While the balance of the structure is made of low-carbon steel, the inner ring is of low-carbon "Cromansil" steel, possessing slight hardening properties, yet having a yield strength of over 60,000 lbs. per sq. in." (Courtesy: Wellman Engineering Co.)

Mayari R is pointed to as readily welded by all the usual methods. The combined strength and corrosion resistance

Table XI.—Carbon and Low Alloy Steels. From Paper Before A.S.T.M., by Cone[3]

Range of Percentage Composition Reported by Companies.

Type	Carbon, per cent	Manganese, per cent	Silicon, per cent	Copper, per cent	Nickel, per cent	Molybdenum, per cent	Phosphorus, per cent[d]	Other Elements, per cent
Carbon Steels:								
S.A.E. No. 1030	0.25 to 0.35	0.50 to 0.80	....	....	....	....	....	....
S.A.E. No. 1015	0.10 to 0.20	0.30 to 0.60	....	....	....	....	....	....
Early Steels:								
S.A.E. No. 2115	0.10	0.30	0.15	....	1.25	....	....	....
2 to 2.5 per cent Nickel	0.20	0.60	0.30	....	1.75	....	....	....
	0.20	0.40	....	....	2.00[b]	....	....	....
	0.20	0.80	....	....	2.00[b]	....	....	....
S.A.E. No. 2300	0.45[a]	....	....	....	3.50	....	....	....
S.A.E. No. 3130	0.25 to 0.35	0.50 to 0.80	....	....	1.0 to 1.5	....	....	0.45 to 0.75 Cr
S.A.E. No. 3115	0.10 to 0.20	0.30 to 0.60	....	....	1.0 to 1.5	....	....	0.45 to 0.75 Cr
S.A.E. No. 4630	....	....	....	....	....	....	....	....
S.A.E. No. 4615	0.10 to 0.20	0.30 to 0.60	....	....	1.5 to 2.0	0.20 to 0.30	....	....
Medium Mn	0.20 to 0.25	1.00 to 1.75	....	....	....	....	....	....
Sil. Struct.	0.30 to 0.40	0.70 to 0.90	0.20 to 0.30	....	....	....	....	....
Cr-V	0.15 to 0.25	0.50 to 0.80	....	....	....	....	....	0.80 to 1.10 Cr, 0.15 V[b]
Cromansil	....	1.00 to 1.40	0.60 to 0.90	[c]	....	....	....	0.40 to 0.60 Cr
Mn-V	0.13 to 0.18	1.20 to 1.45	0.15 to 0.25	....	....	....	....	0.09 to 0.12 V
C-Mo	0.08 to 0.15	0.70 to 0.90	0.20 to 0.30	0.20[c]	....	0.20 to 0.30	....	....
Mn-Mo	0.10 to 0.20	1.20 to 1.40	0.20 to 0.30	0.20[c]	....	0.20 to 0.30	....	....
Steel Companies' Steels:								
Cor-Ten	0.10	0.10 to 0.30	0.50 to 1.00	0.30 to 0.50	....	....	0.10 to 0.20	0.50 to 1.5 Cr
Man-Ten	0.35[a]	1.25 to 1.70	0.10 to 0.30	0.01 to 0.25	....	0.00 to 0.40	....	0.00 to 0.20 V
Sil-Ten	0.20 to 0.40	0.40 to 0.80	0.20[b]	0.01 to 0.25	....	....	....	....
Yoloy	0.08 to 0.22	....	....	1.0	2.0	....	....	....
RDS-1	0.12[a]	1.00[a]	....	0.5 to 1.5	0.5 to 1.0	0.20[a]	....	....
RDS-1A	0.30[a]	1.00[a]	....	0.5 to 1.5	0.5 to 1.0	0.20[a]	....	....
Hi-Steel	0.12[a]	0.50 to 0.70	0.30[a]	0.9 to 1.25	0.45 to 0.65	....	0.10 to 0.15	....
HT-50	0.12[a]	0.15 to 0.90	Trace	0.30 to 0.80	0.30 to 0.80	0.05 to 0.25	0.05 to 0.15	....
AW 70-90 A } AW 70-90 B }	0.25[a]	0.75[a]	0.25[a]	0.30 to 0.50	0.25[a]	....	0.08 to 0.10	0.25 Cr[a]
Jal-Ten	0.35[a]	1.25 to 1.75	0.30[a]	0.40[b]	....	....	....	....
Granite City HS 1	0.14	0.70 to 0.90	0.15 to 0.20	0.25 to 0.30	....	....	....	0.12 Cr
Granite City HS 2	0.20 to 0.30	1.20 to 1.60	0.15 to 0.20	0.25 to 0.30	....	....	....	0.12 Cr
Centralloy	0.08 to 0.30	0.60 to 0.90	0.50[a]	0.40 to 0.60	0.25[a]	Yes	....	0.25 Cr[a]
Konik	....	....	....	0.10 to 0.30	0.20 to 0.50	....	....	0.07 to 0.30 Cr

[a] Maximum.
[b] Minimum.
[c] Optional.
[d] Phosphorus and sulfur range is 0.035 to 0.055 per cent, max., unless otherwise given.

allow weight savings of from 25 to 50 per cent, depending on design and application. Owing to its ductility, it can be fabricated by the methods used in the average shop. It can be handled in the same manner as mild carbon steel —an important point—with only minor variations to allow for greater toughness. The abrasion resistance is 30 to 50 per cent greater than that of mild carbon steels.

"A. W. Dyn-El"—Alan Wood Steel Co.

The Alan Wood Steel Co., Conshohocken, Pa., announces that the earlier steels, A. W. 70-90 A and B, have been discontinued and have been replaced by A. W. Dyn-El. The chemical composition is as follows:

	Range	Typical
Carbon	0.11 to 0.14	0.12
Manganese	0.50 to 0.80	0.60
Phosphorus	0.06 to 0.10	0.085
Sulphur	0.04 max.	0.03
Copper	0.30 to 0.50	0.40

Depending on gage thickness the yield point varies from 51,800 to 60,150 lbs. per sq. in. and the tensile strength from 67,890 to 78,020 lbs. per sq. in. and the elongation in 8 in. from 20.0 to 23.0 per cent and in 2 in. from 25.0 to 34.5 per cent. Other properties are given in Table 2 and in a booklet published by the company. Excellent corrosion, forming and welding qualities are claimed.

Several applications of this steel are reported under construction.

Great Lakes High Tensile— Great Lakes Steel Corp.

A few months ago the Great Lakes Steel Corp., Ecorse, Detroit, announced by advertisements in trade papers a new high tensile steel. No distinctive trade name has yet been made public nor have any data as to its composition been published.

Permission has been given to present a few facts, however. The composition has not been revealed except that it is a low alloy steel. It is reported to possess excellent ductility, combined with high yield point and ultimate strength; to be inherently fine grained; to be capable of cold pressing in various shapes such as auto wheels, etc., without intermediate annealing; and to have excellent welding qualities, without air hardening.

In Table 2 some of the reported physical properties are given. An interesting statement is that giving quick tensile tests at high temperatures (0.505 in. section). From 85 to 800 deg. F. the yield point range was 44,750 to 61,500 lbs., the tensile strength from 76,000 to 81,750 lbs. per sq. in., the elongation in 2 in. 28.2 to 36.0 per cent, and reduction of area 61.8 to 71.0 per cent.

Wheels for automobiles have been cold pressed from the new steel, "fatigue tests on which have shown 3 to 5 times the life of carbon steel wheels." The resistance of welds of this steel to impact is illustrated by the dropping of a large tank, filled with 150 gal. of water, from the height of 28 ft. on to a steel plate. It did not fracture until the fifth drop. A photomicrograph is furnished to reveal its inherent fine grain.

General Remarks

THE foregoing presents, rather briefly and not completely, the present status of the large variety of low alloy high strength (high elastic) steels. The presentation is based, as said before, on replies to a questionnaire sent to the various companies interested.

Some months ago the writer had the privilege of visiting the plant of the Wellman Engineering Co., Cleveland, a company which, since the early introduction of these steels, has had a broad experience in incorporating these steels in various structural products, mostly by welding. The president, Mr. A. E. Gibson, showed numerous examples of large equipment made of these steels and was enthusiastic as to their serviceability and future application. We are able to reproduce one or two illustrations of these products, through his courtesy and cooperation.

During the season of 1936-1937, a well known member of one of the large American technical societies delivered an address before a local chapter of that society. His subject was low alloy steels with particular reference to the class of steels treated in this article. He did not look with favor on most of these steels, criticized (and justly) some of the claims made for them, broadcast the impression that in his opinion they could not amount to much, and said that, whenever they were mentioned, he could with difficulty "suppress a yawn." It would seem that subsequent developments must surely have awakened this lecturer to the present and future role of at least some of these steels.

This survey shows that there are about 16 so-called "company steels" or steels promoted by steel companies and about 4 types which are sponsored by alloy companies or by other promoters—truly an impressive array.

Some of them, as has been partially demonstrated in the foregoing, are being extensively used—in both passenger and freight cars, in tanks cars, in trucks, in buses, in bridges, in pressure vessels, in mine and other equipment and so on,—primarily anywhere where lightening the carrier and increasing the pay load as well as combating corrosion and facilitating the use of welding is a consideration.

Not all of these steels are likely to survive—in this as in some other fields it will be the "survival of the fittest." Many of them have been improved. But the whole development is one of the most important in the steel industry in many years and its future is certainly bright.

References

[1] "Trends in the Metallurgy of Low Alloy, High Strength Structural Steels" by H. W. Gillett, Battelle Memorial Institute, Columbus, O. A.I.M.E. February, 1936, meeting.

[2] "Choosing a Composition for Low-Alloy, High Strength Steel" by S. Epstein, J. H. Nead and J. W. Halley. A.I.M.E. February, 1936, meeting.

[3] "Carbon and Low Alloy Steels" by Edwin F. Cone, *Metals and Alloys*, New York. Paper before A.S.T.M. Spring Committee Meetings, Pittsburgh, March 4, 1936.

[4] "Low Alloy, High Yield-Strength Structural Steels—An Extended Abstract." *Metals and Alloys*, Vol. 7, March, 1936, pages 77 to 84.

HANDLING SOLID CARBURIZER IN

Continuous Box Carburizing

by R. H. Weber

General Foreman, Heat Treating
Cadillac Motor Car Division
Cadillac Motor Co., Detroit

IN THE PRESENT DAY of industrial change, it is not always practical to scrap old equipment and processes to take advantage of new ideas, however attractive the latter may be. There are open in many instances, however, avenues of modernization that reach the same goal at surprisingly low cost.

Many interesting and well-founded claims have been advanced for new methods of carburizing. Forgetting for a moment these claims, yet cautiously remembering the intricacies and variables of the new processes, let us consider an improvement in the time-tested carburizing method known as box carburizing.

At Cadillac we have installed a unique, improved cycle for the travel of solid compound in the carburizing of transmission and rear axle gears. The furnace used is a gas-fired continuous pusher type having four tracks. With a carburizing temperature of 1675 deg. F., a total furnace time of 11 hrs. is required to obtain a case depth of 0.040 in. The pushes are made every 44 min. per track and are staggered 11 min. apart to facilitate manual operations on the unit as a whole.

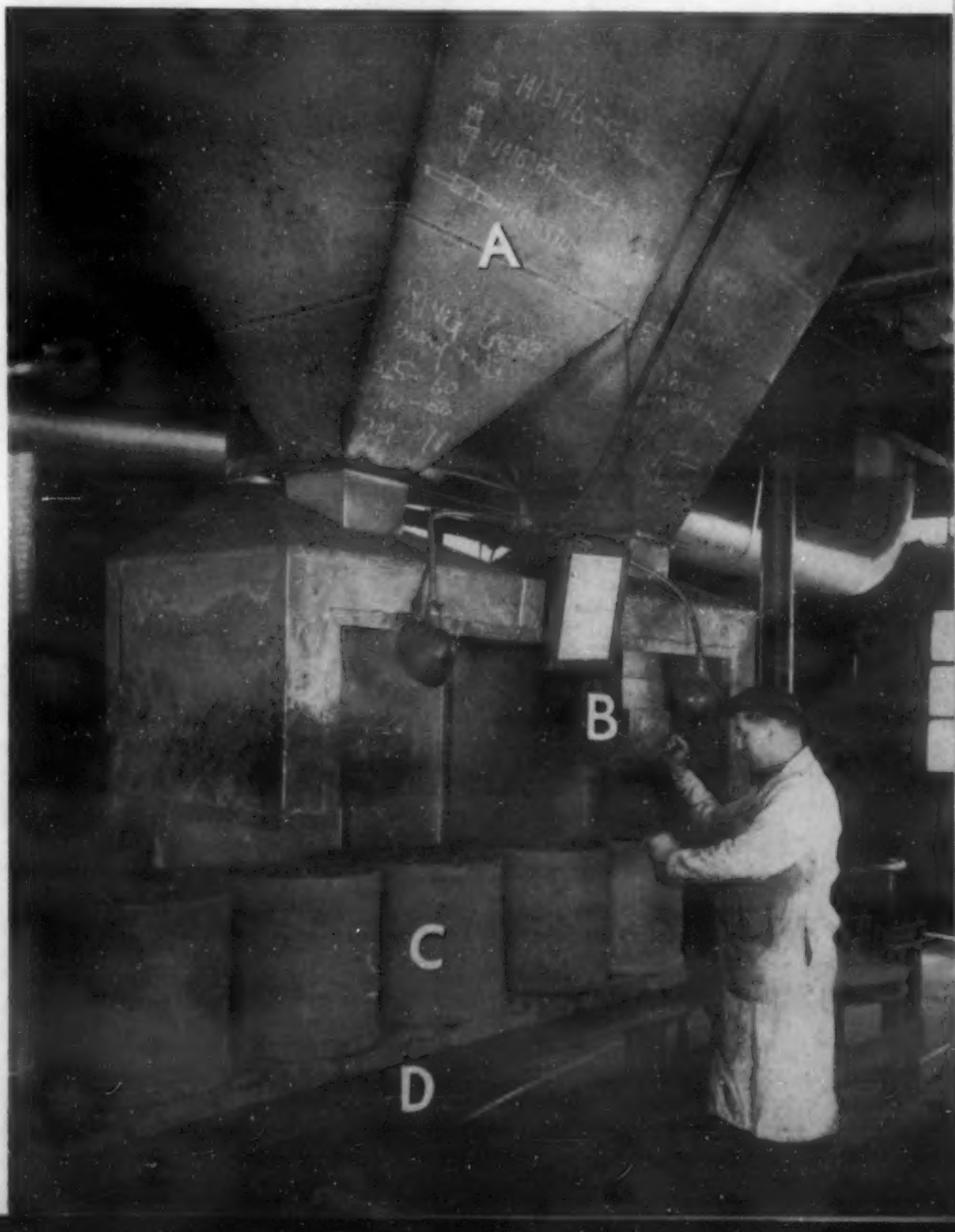
Because quality and efficiency are the two essentials, a modification in pot design that improved both deserves mention. Where formerly square or rectangular boxes were used—and there are many units that still employ them—a cylindrical heat-resistant alloy pot is now used. Warping and buckling of pots is virtually unknown and, coupled with the uniformity of heating which is proved by the quality of the finished gears, the improvement is one that merits the attention of all heat treaters.

The compound is a standard charcoal base type containing 25 per cent maximum coke, 10 per cent barium carbonate and 5 per cent calcium carbonate. A noteworthy improvement regarding this compound is its size. Known commercially as No. 2 size, the particles are at least $\frac{1}{2}$ in. in diameter, a size which considerably reduces density in packing. As the compound is purchased by weight and used by volume, the use of this size has resulted in at least 10 per cent decrease in volume cost. Not only is time and expense reduced, but the increase in void volume makes possible a more adequate and uniform circulation of the carbonaceous gases.

Loading and Conveying

Two of the round heat-resistant pots, which as we shall see later never leave the tray on which they rest, are moved

Fig. 1. Round Heat-Resistant Pots Travel on Trays on a Conveyor to Positions under the Chutes. (Courtesy: Claude B. Schneible Co., Chicago)



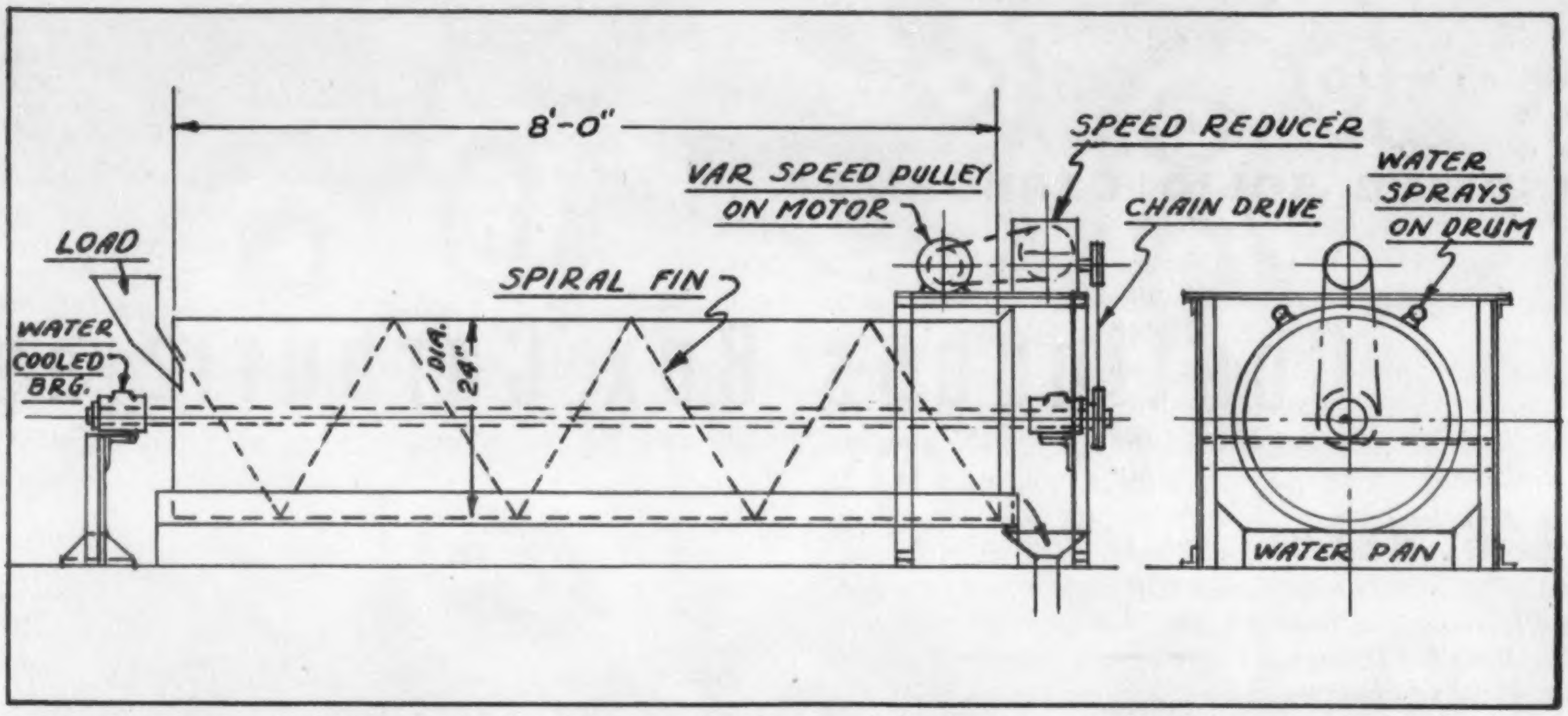


Fig. 2. Details of the Rotary Cooling Drum at the Bottom of the Hopper. In this the compound is cooled from about 1100 deg. F. (Courtesy: Claude B. Schneible Co., Chicago)

on a roller conveyor to a position under the chute A (see Fig. 1). This chute empties the bin located in the balcony above, and by simple lever action the compound is released from the small orifice (B) into the waiting pots (C). The parts are held on alloy hair-pin fixtures so designed as to facilitate direct quenching from the pot. The pots, now completely packed, are moved by gravity down the conveyor (D) which places them into position for an air hoist easily to lift them onto one of the tracks of the furnace.

After 11 hrs. in the furnace, the tray emerges from the unload end and is again hoisted and set on the floor, from which position the parts are removed by simply lifting the hair-pin fixtures, and quenched. The tray containing two pots of red hot compound is now lifted by the same hoisting method and moved to a gravity conveyor. In traveling the 90 ft. of this conveyor's length, the compound has

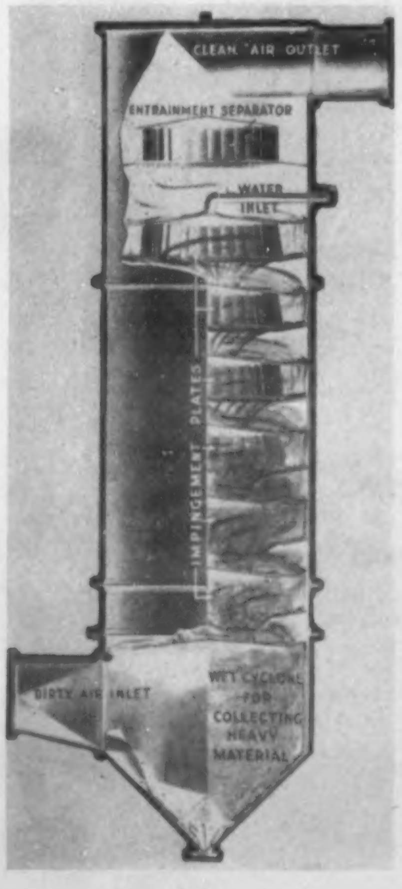


Fig. 3. Specially designed Dust Collector for Carrying Off Dust and Fires. (Courtesy: Claude B. Schneible Co., Chicago)

cooled from about 1500 deg. F. to approximately 1100 deg. F. It has now reached the dumping station; here the pots, still on the tray, are upset in an air-operated turnover fixture which dumps the hot used compound into a hopper below the floor. The pots are then returned to an upright position and sent on the roller conveyor back to the packing station from which they started.

Cooling the Used Compound

Let us return now to the compound that was just dumped into the hopper at a temperature of 1100 deg. F. At the bottom of the hopper, the compound is guided through a funnel-shaped chute, made small at the lower end, which regulates the flow into a rotary cooling drum, shown in detail in Fig. 2. As this drum slowly revolves, two projections on its circumference trip a hammer which knocks on the small chute mentioned above and prevents the compound from jamming in the small orifice. The drum is completely covered by a water-tight sheet metal housing, directly under which two pipe lines on either side of the drum spray it with water. In keeping with efficiency, the water used to cool this drum is caught in a drip trough and utilized in another part of the system, which will be explained later. This system is capable of cooling 1800 lbs. of compound from 1100 deg. F. to 175 deg. F. in 1 hr.

Separating the Fines

As it emerges from the cool end of the drum, the compound is blown by a compact but powerful blower up a distance of 40 ft. through a 7-in. pipe to the top of the separator where the compound strikes a baffle. The heavy particles then fall to the bottom of the separator and a chute conducts them onto a moving leather belt. This belt is about a foot wide and moves over a magnetized drum designed to hold all particles of steel and deposit them into a small hopper beneath the belt, while the cooled and dust-free compound with all steel particles removed falls from the end of the belt into the bin—which is the place from which it started.

There is still one part of the journey of the carburizing

compound that has not been described—that is the side road that the dust and pulverized particles of compound (which are hindrances to good carburizing) take when separated from the usable compound. At the top of the separator, a suction pipe carries off the refuse of dust and fines along with the dust collected by a tributary suction pipe over the loading station, and is blown into a specially designed dust collector, shown in Fig. 3. This dust collecting tower is approximately 25 ft. high and 6.5 ft. in diameter. Inside this shell with a cone-shaped bottom are 6 impingement plates, which collect and precipitate the foreign particles of dust and fines that are carried in the air blown into the bottom of the tower. As the dirty air makes its cyclonic ascent, down-coming water is reduced to a fine spray, which washes the air and carries the dirt and dust as a sludge to the cone-shaped bottom of the tower.

Of the 30 gal. of water per min. required, 8 gal. per min. are obtained from the collected cooling water of the rotary compound cooler as already mentioned. The amount of air passing through the tower, 10,000 cu. ft. per min., must be kept constant for efficient operation. The problem of checking this was easily solved when a small pipe, inserted into the large blower pipe and leading to a U-tube pressure indicator, was marked for operating limits as checked against the proper cu. ft. per min. reading of a velometer. This precaution was taken in anticipation of possible belt slipping or similar failures that would decrease the velocity of the blower.

Even from this brief picture, it can be seen that this entire system is one of unusual efficiency and economy. Manual labor and handling time have been reduced to a minimum; cleanliness and ease of operation make for better and more pleasant working conditions. And while savings in compound costs and scrap losses have more than paid for this installation, its outstanding attribute is the uniformity and consistently high quality of the finished product.

Editorial

(Continued from page A 11)

Magnets in radio speakers, dry batteries and storage batteries, tungsten lamps and photographic flash lamps, sterling silver and silver plate, platinum iridium rings, white and yellow gold rings and watch cases, bring in various metals, while the sparking points for cigarette lighters involve cerium. One lighter is made of "Durium," whatever that is, and another example of vagueness is in the "Indestructo" metals for firepots of furnaces and burners of stokers. They'll send you a chunk of Indestructo and of cast iron so you can try a hacksaw on both and see how much harder the former cuts, whatever that has to do with heat-resistance.

The motor boat section lists bronze propellers, Al pistons, bronze connecting rods, Ni-Cr steel crankshafts, stainless steel pumps, etc. In the automobile section, brass and copper alloys in radiators, Al pistons, heat-resisting valves, Si-Mn steel springs, die cast carburetors (some dichromate treated), re-babbitted connecting rods, etc., occasion no surprise. In the tools we have V steel saws, Al levels and rules, Mn steel hammers, Cr-plated auger bits, Cr-V steel wrenches, soldering coppers, solder and babbitt, brass stencils, and tungsten steel hack saw blades. The omission of Mo steel hacksaw blades and of austempered shovels should be looked into by Emmons and Davenport, respectively.

Tinware, Al, and stainless steel compete in cream separators. The plowshare page is headed by pictures of an L. and N. recorder and a Rockwell instrument. We couldn't find any hard-faced plow shares or cultivator teeth, though hard water soap is listed.

A wagon truck is electrically welded. Copper-bearing steel fences galvanized after weaving and Parkerized steel coal chutes are listed. Malleable iron comes in for harness snaps. A lathe bed is "semi steel." Horse shoes are drop forged steel. "Iron" for blacksmith's use is listed, but it is not stated whether this is wrought iron or not. Incidentally, any foundryman who wants to buy a cold shut can find it on page 1028.

A four page pink insert, in the back, features lower prices on nails, fence, fence wire and barbed wire, copper-bearing steel pipe, steel roofing, etc., in line with reductions announced by the steel companies while the book was in press.

The search for applications of modern metallurgy in this list of things in every day use reveals a considerable number, though we failed to find anything listed made from a magnesium base alloy. One wonders in how many cases the metallurgical terminology is used because the purchaser intelligently connects it with quality, and in how many just because it's a nice mouthfilling word.

While the metallurgical engineer may not be interested in a formal "Prom Trotter" in Celanese Rayon Satin, "just packed with girlish appeal" for $3.98, (p. 38) he will find the products of his art on later pages, usually less glamorously described.—H.W.G.

Scrap Iron and Steel

The American scrap iron and steel industry has, in recent years, expanded to such an extent that it is now of major importance—both as to domestic consumption and as to exports. Scrap stands today in the front rank among the raw materials of the world's steel industry. Its greater use, both in iron furnaces and in steel-making furnaces, has resulted in measurable conservation of iron ore and other materials.

As to domestic consumption—over 38,006,000 gross tons of scrap was consumed in 1937 of which 28,368,000 tons or 74.6 per cent went into steel furnaces. The corresponding data for 1936 are 36,358,000 tons consumed, of which 27,782,400 tons or 76.5 per cent went into steel melting operations. If comparisons with data for 15 to 20 years were at hand, it would be found that present-day percentages are far in excess of those of earlier periods.

It is, however, in export business that the most interesting and startling developments have taken place. The first recorded exportation of scrap iron and steel was in 1896 or 42 years ago when scrap to the value of only $11,389, went to Canada, Italy, United Kingdom and China. Gradual expansion took place so that, in the 34-year period, 1900 to 1933, the export total was approximately 4,455,000 gross tons, the highest for any of these years having been 773,000 tons in 1933.

These data pale into insignificance before the figures for quite recent years. Exports in 1934 jumped to 1,835,000 tons, expanded to over 2,103,900 tons in 1935, shrinking a little to 1,936,000 tons in 1936. In 1937, however, a

(Continued on page 262)

One of the Transcontinental & Western Air's All-Aluminum Twin-Motored Douglas Transport Planes. (Courtesy: Aluminum Co. of America)

Airplane Propeller Blade Life

by J. B. Johnson and T. T. Oberg

Air Corps, Wright Field,
Dayton, Ohio.

The importance of the life of the propeller blades of an airplane cannot be too strongly emphasized. They are subjected to combined stresses due to centrifugal, bending and torsional loads, the magnitude of which can be determined only approximately. There is also the factor that the properties of the precipitation hardened aluminum alloys change with age and that this change may be hastened by vibrations. Failures of such blades have been comparatively rare since an intensive study has proved that they were due to repeated applications of stress rather than impact or suddenly applied load and to stress raisers. Operators consider the useful life for aluminum alloy propeller blades at about 4,000 hours.

The authors of this article, experts in their field, compare tests on two blades from the same alloy, each varying decidedly in length of life.—The Editors.

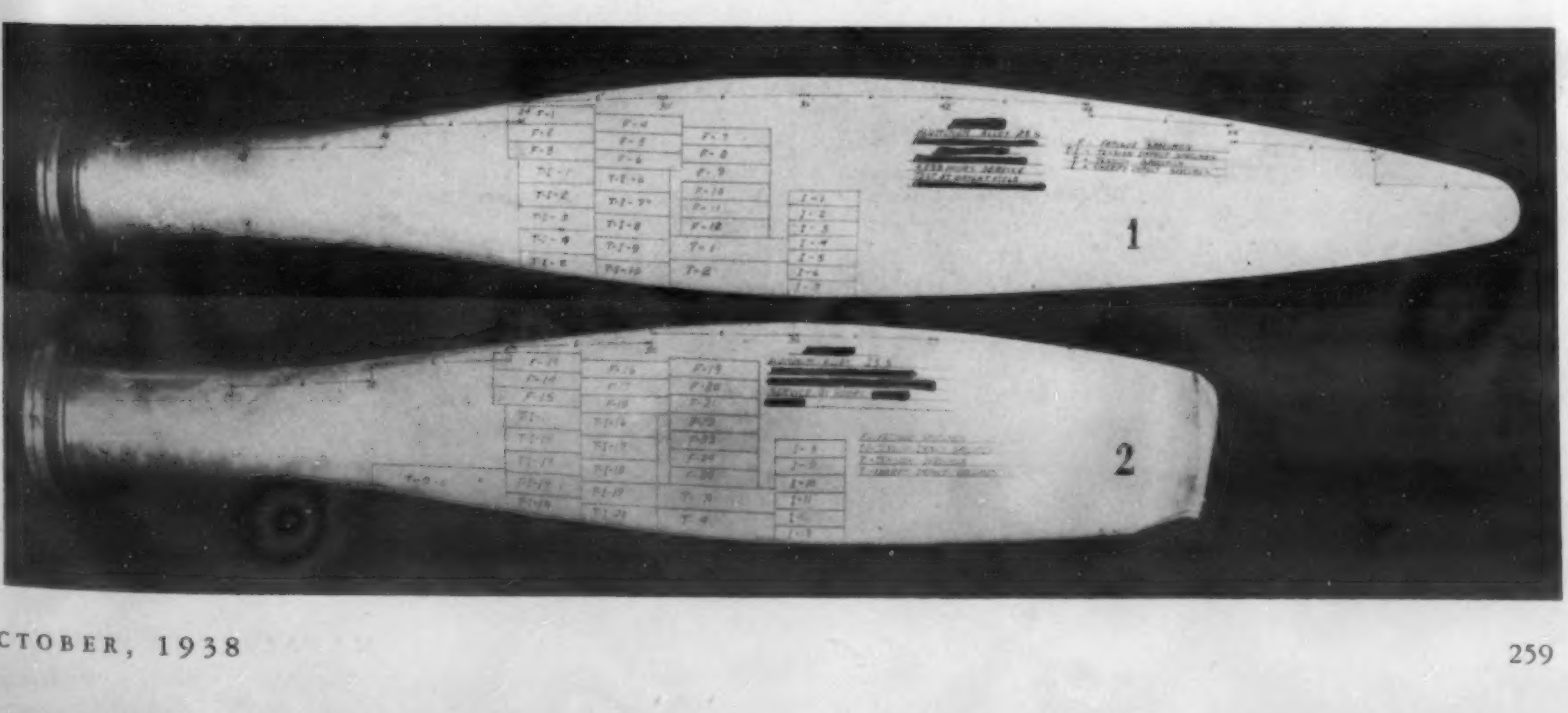
THE AIRPLANE PROPELLER BLADE is a tapered airfoil section which is subjected to combined stresses due to centrifugal, bending and torsional loads, the magnitude of which can only be calculated approximately. The failure of a propeller generally involves a forced landing, which may lead to further damage to the airplane or engine. These two factors, together with the assumption that the properties of the precipitation hardened aluminum alloys change with age and that vibration may accelerate this change has caused airline operators to consider the useful life for aluminum alloy propeller blades at approximately 4,000 hrs.

No convincing evidence has been produced that the mechanical properties of the material in a propeller blade are affected by service, although many tests have been conducted on used blades. A test was recently completed at Wright Field of two blades manufactured from the same alloy and representative of modern forging practice. One of these blades was flown on an experimental airplane and had 21 hrs' service, whereas the other was removed from service by a commercial airline after 4,233 hrs.' flying time.

The blades were manufactured by a process of rolling and forging, followed by a solution heat treatment, and aging at elevated temperatures. The chemical compositions were almost identical as given in the Table. The test specimens to determine the mechanical properties were taken from the section of the blades in which the stresses are equal to or above the average stress in other parts of the blade, Fig. 1.

There is a difference in grain size and distribution in the two blades as indicated in Figs. 2 and 3, but this has no

Fig. 1. Location of Test Specimens in Blades.



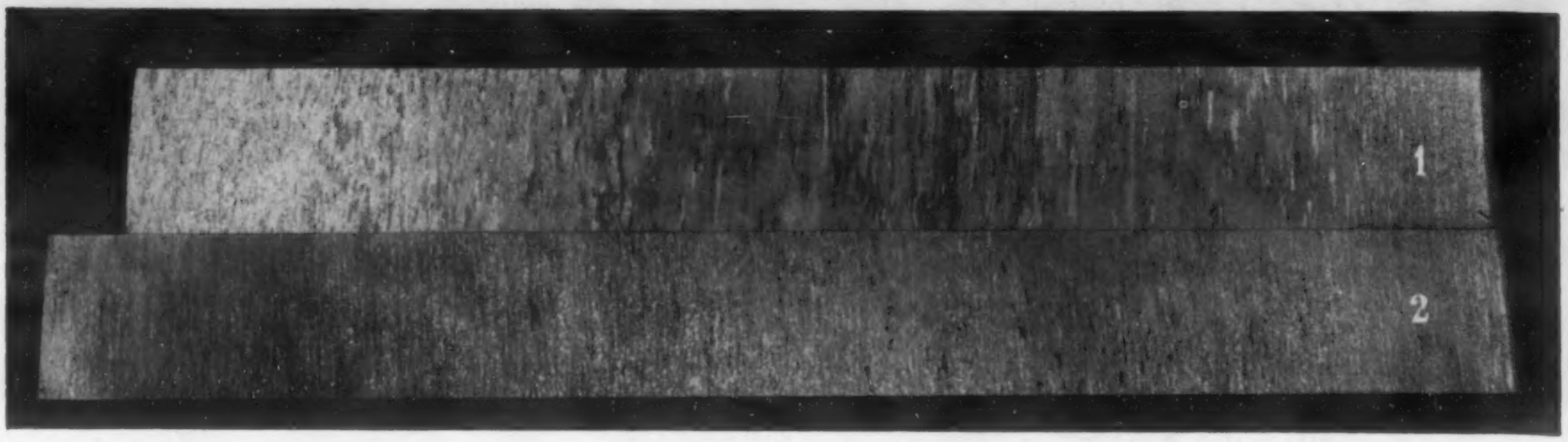


Fig. 2. Comparative Grain Size of the Two Blades—Longitudinal Section. Etched with HCl + HNO₃ + HF. No. 1—4233 hrs; No. 2—21 hrs.

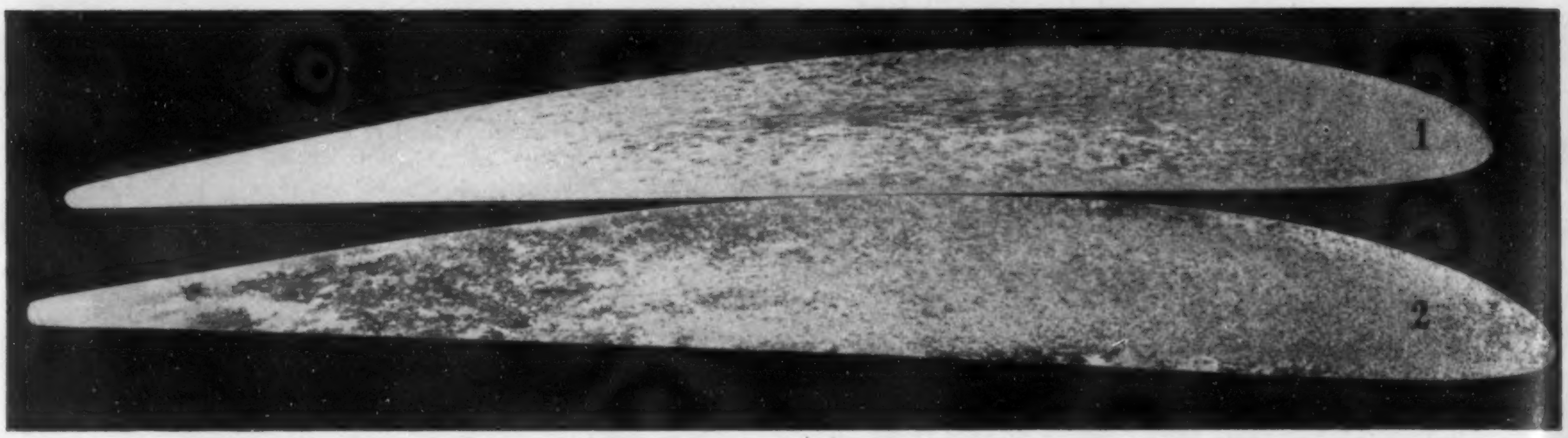


Fig. 3. Comparative Grain Size of the Two Blades—Transverse Section. Etched with HCl + HNO₃ + HF. No. 1—4233 hrs; No. 2—21hrs.

apparent effect on mechanical properties. The microstructure, Fig. 4, is normal for forged alloys of this chemical composition.

The S-N diagrams, Fig. 3, indicate better endurance properties for the blade with the longer service. Both curves, however, fall within the area which has been found to represent the fatigue characteristics of this alloy. The specimens which did not fail at the lower stresses after operating to 500,000,000 cycles were retested at a higher stress, the loading being accomplished without stopping the machine. The fatigue limit was selected at the stress at which no damage resulted from original test at 500,000,000 cycles, as indicated by the retest.

The transition velocity curves were obtained by Watertown Arsenal, U. S. Army, Ordnance Department, on standard specimens.* The differences in the transition velocity curves cannot be interpreted at the present on account of the lack of data on aluminum alloys.

The effect on the material of over-loading propeller blades has also been studied by the laboratory method of

Fig. 4. Microstructure. 100 X. No. 1 (Left)—4233 hrs; No. 2—21 hrs.

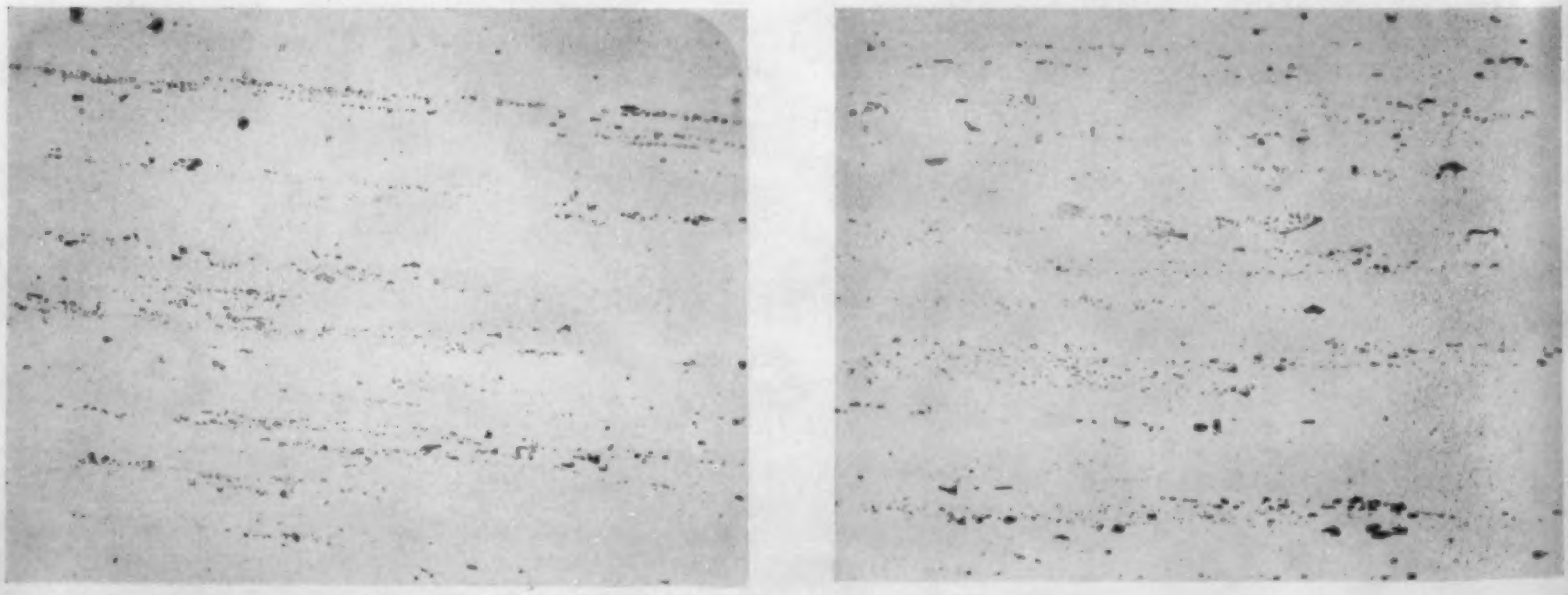
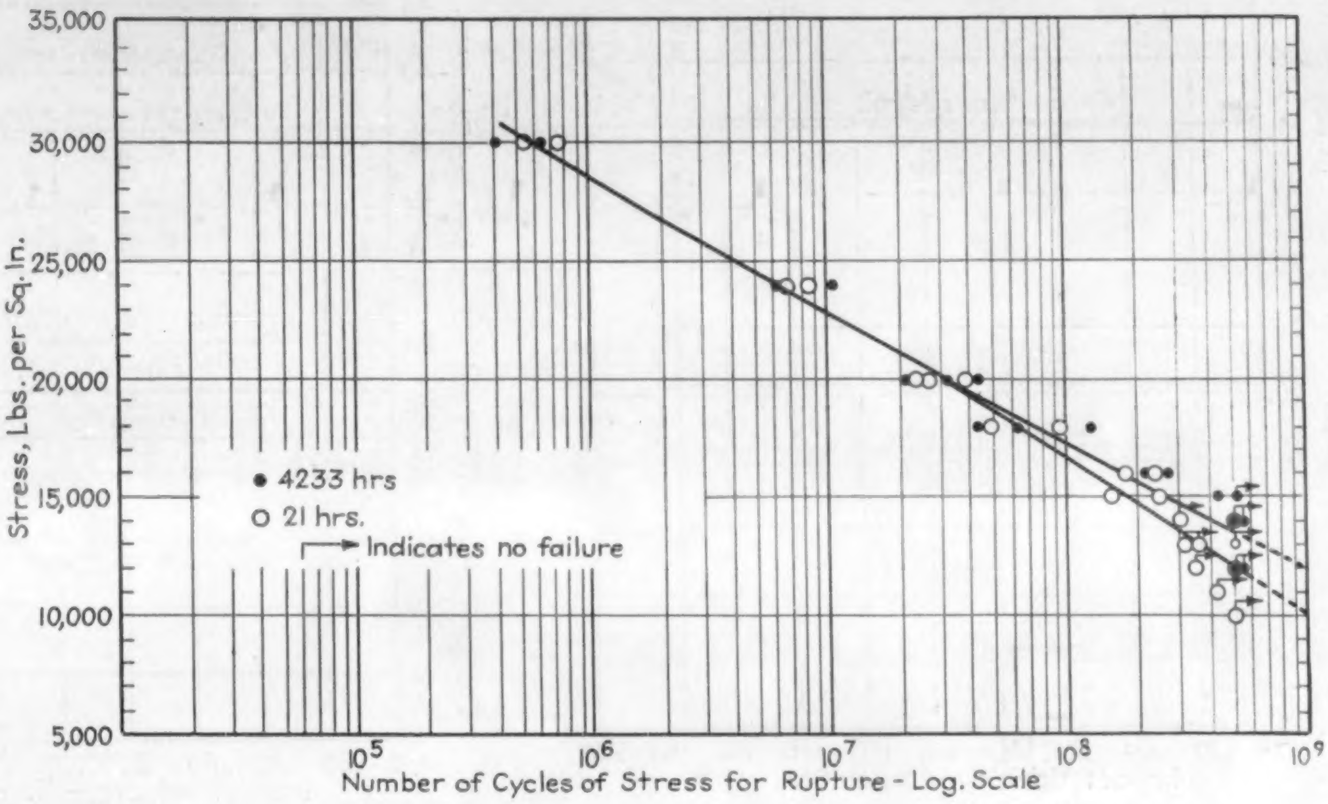


Fig. 5. SN Diagram for Propellers from Service—Log Scale.



determining the damage to fatigue life from over-stress. The S-N diagram, Fig. 6, was obtained from specimens cut from a forged heat-treated aluminum alloy bar, 6 in. in diameter, of approximately the same composition as given in the Table.

The stress and number of cycles for the original test are shown in each case. The retests are not plotted but results of the retest are indicated by the shape of the point. If the specimen did not fail in the original test (circles) it was retested at a stress 30 to 50 per cent lower or higher than the original and run until failure occurred. If the failure was to the left of the S-N diagram drawn through the circles the specimen had been damaged (triangles), that is, the fatigue resistance lowered by the original test, if to the right, no damage (semi-circle).

Example A. (Fig. 6)—The specimen failed on the original test at 26,000 lbs. per sq. in. and 350,000 cycles; *Example B*—the specimen was run at 26,000 lbs. per sq. in. for 220,000 cycles without failure, the load was reduced at 18,000 lbs. per sq. in. and the test continued to failure at 942,900 cycles, which is to the left of the S-N diagram. The original test had damaged the specimen, the retest is not plotted; *Example C*—two specimens were run at 22,000 lbs. per sq. in. to 500,000 cycles, one was retested at 16,000 lbs. per sq. in. and the other at 14,000 lbs. per sq. in., the first failed at 50,559,200 cycles and the second at 269,600,000 cycles, both of which are to the right of the S-N diagram, indicating no damage on the original test.

There are cases where no damage was indicated by a retest when the first test of the specimen may have actually been run longer at this stress than some other specimen which failed on the original test. *Example D*—This is characteristic of all fatigue data on aluminum alloys, the scatter of results is so large that overlapping is to be expected. An S-N diagram established from sufficient data to represent the minimum boundary of the zone of scatter will also represent very closely the boundary of no damage.

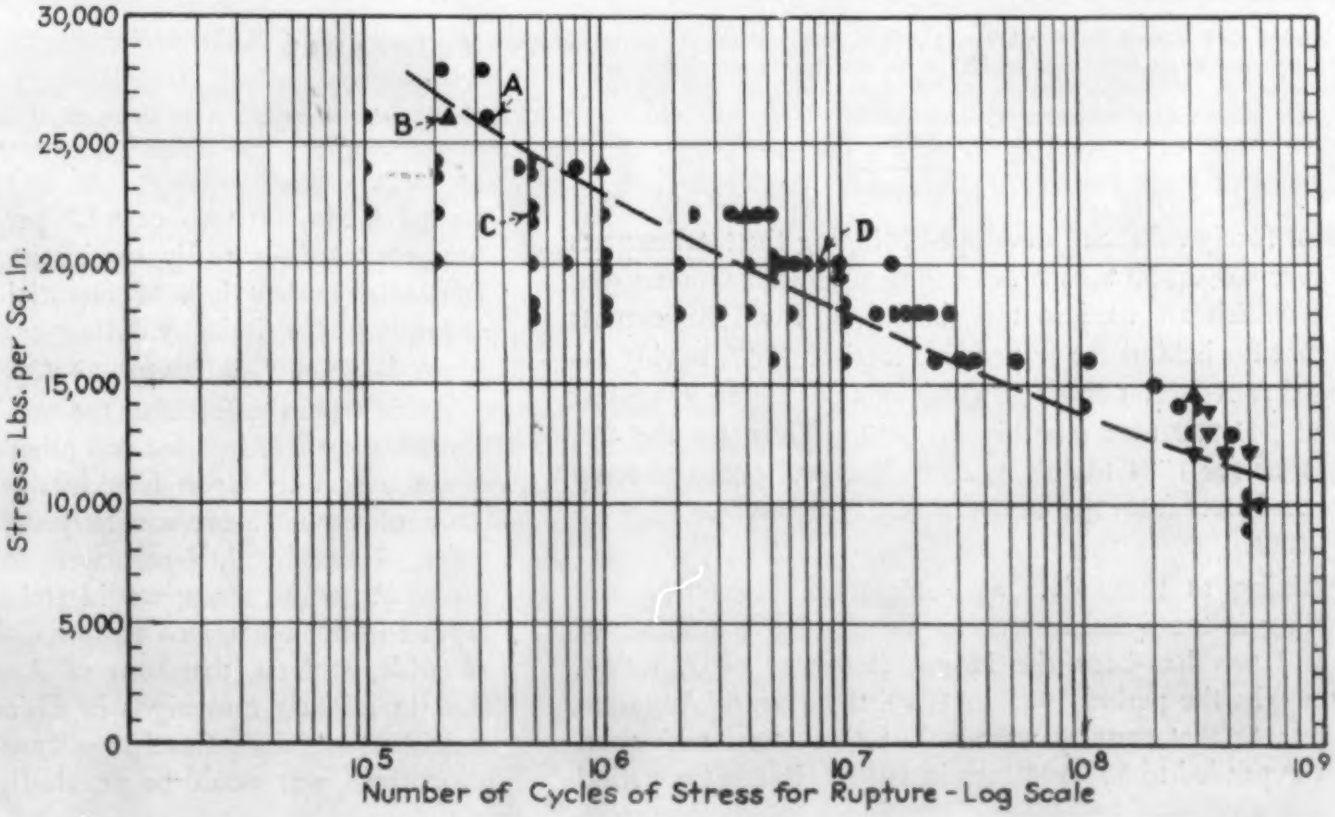


Fig. 6. SN Damage Diagram for Forged Aluminum Alloy — Log Scale.

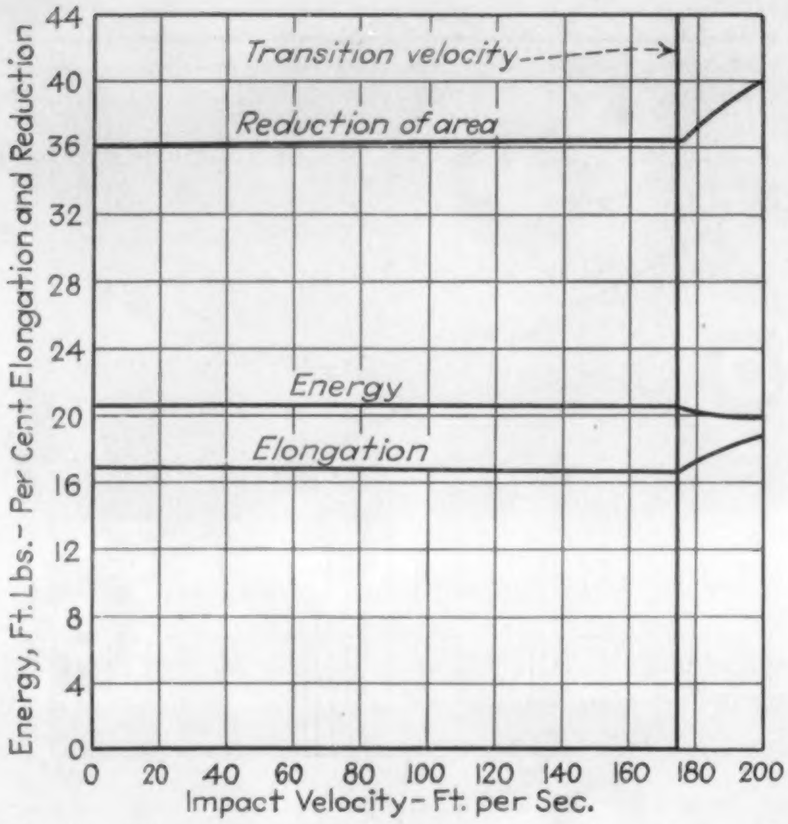


Fig. 7. Transition Velocity Aluminum Alloy Blade with 4233 hrs.

TABLE OF AVERAGE PROPERTIES OF AIRPLANE PROPELLERS

		Max. Deviation, Per Cent		Max. Deviation, Per Cent
Hours service	21		4,233	
Chemical composition:				
Copper	4.38		4.17	
Iron	0.48		0.47	
Manganese	0.71		0.75	
Silicon	0.93		0.82	
Aluminum (by diff.)	93.50		93.79	
Longitudinal	.....			
Tensile strength, p.s.i.	58,300	1.5	55,300	8
Yield strength (set 0.002) p.s.i.	38,600	7	38,500	7
Prop. limit (set 0.0001) p.s.i.	29,900	6	32,400	5
Elongation 4d, per cent	18.2	4	16	10
Red. of area, per cent	29.8	3	27	5
Brinell hardness	116	1	115	2
Fatigue limit, rotating beam	10,000	..	12,000	..
Charpy impact, notched, ft.-lbs.	9.93	5	9.34	5
Charpy impact, no notch, ft.-lbs.	96.13	2	95.95	16
Transverse	.....			
Tensile strength, p.s.i.	.....		58,000	6
Yield strength (set 0.002) p.s.i.	.....		39,100	0.3
Prop. limit (set 0.0001) p.s.i.	.....		31,700	0.3
Elongation 4d, per cent	.....		13.5	3
Red. of area, per cent	.....		16.9	2
Charpy impact, no notch, ft.-lbs.	55.38	7	47.82	10

Impact specimens 0.394 in. (10 mm.) sq. Notch 0.197 in. (5 mm.) deep with radius at bottom of 0.0395 in. (1 mm.). The maximum deviation is on the difference between the average value and the largest or smallest value for an individual specimen.

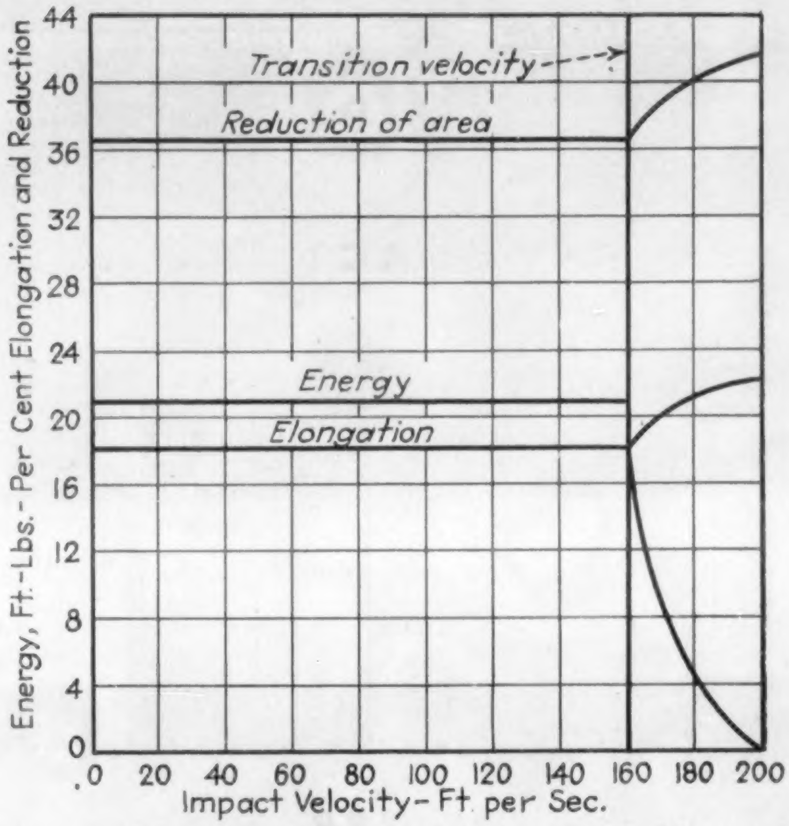


Fig. 8. Transition Velocity Aluminum Alloy Blade with 21 hrs.

These data would indicate that an aluminum forging alloy of this chemical composition and heat treatment is not damaged by over-stress.

Propeller blade failures have been comparatively rare since an intensive study proved that they were due to repeated applications of stress rather than impact or suddenly applied loads and were caused by stress raisers, such as too abrupt change of section between shank and blade, galling between propeller hub and shank of blade, surface damage from stones or other obstacles and nodes of high stress due to operating in the range of the critical frequency of the blade.

Stress raisers can be eliminated by care and experience in design and avoiding flying for any appreciable time at the critical speeds. If fatigue cracks have started they can be detected by a light etching with an alkaline solution. Unless a crack has formed, it may be assumed that the metal has not been damaged.

Reference

* "High Velocity Tension Impact Tests." H. C. Mann. *Proc. Am. Soc. Testing Materials*, Vol. 36, Pt. II, 1936.

(Continued from page 257)

major foreign demand developed bringing the total exports to over 4,092,500 tons. According to official Government data, which are used in this discussion, the 1938 exports are not far behind the stupendous total of 1937, having averaged to August 1 about 275,000 tons per month as against about 341,000 tons monthly in 1937. Thus, for the 4½ years, or for 1934 to July 1, 1938, the total outgo of scrap iron and steel from the United States approximates 12,000,000 tons.

Striking as these data are, still more interesting and startling is the quantity sent to Japan. For a number of years Japan has been the largest consumer of American scrap. In the period 1925 to 1929, the average American exports to that country were only 93,341 tons each year. This expanded to 547,500 tons in 1933. But in the period of large expansion—1934 to 1937 inclusive—Japan absorbed 5,255,600 tons or 52.7 per cent of the 9,967,800 tons exported—a really significant total. This is due of course to Japan's lack of essential raw materials for her expanding steel industry. Italy and Great Britain are also recent large purchasers of our scrap.

Aside from the fact that the use of scrap, both here and abroad, conserves iron ore and other raw materials, the large quantity sent to Japan is of major interest from another point of view. Scrap can be justly considered a war material. Undoubtedly Japan, were she deprived of the supply of American scrap, would at least be decidedly handicapped in her operations against China. It is not a matter of pride, at least, that tons of American scrap are being used in military campaigns in China and Spain. If noncombatant nations refused to sell war materials to contending nations, war would be practically impossible.—E. F. C.

THE MANUFACTURE OF

Nickel-Chromium Resistance Wire

— A PICTORIAL DESCRIPTION

Photographs
by Don Graf and George Miller

Reinhold Publishing Corp., and Wilbur B. Driver Co., Newark, N. J., Respectively

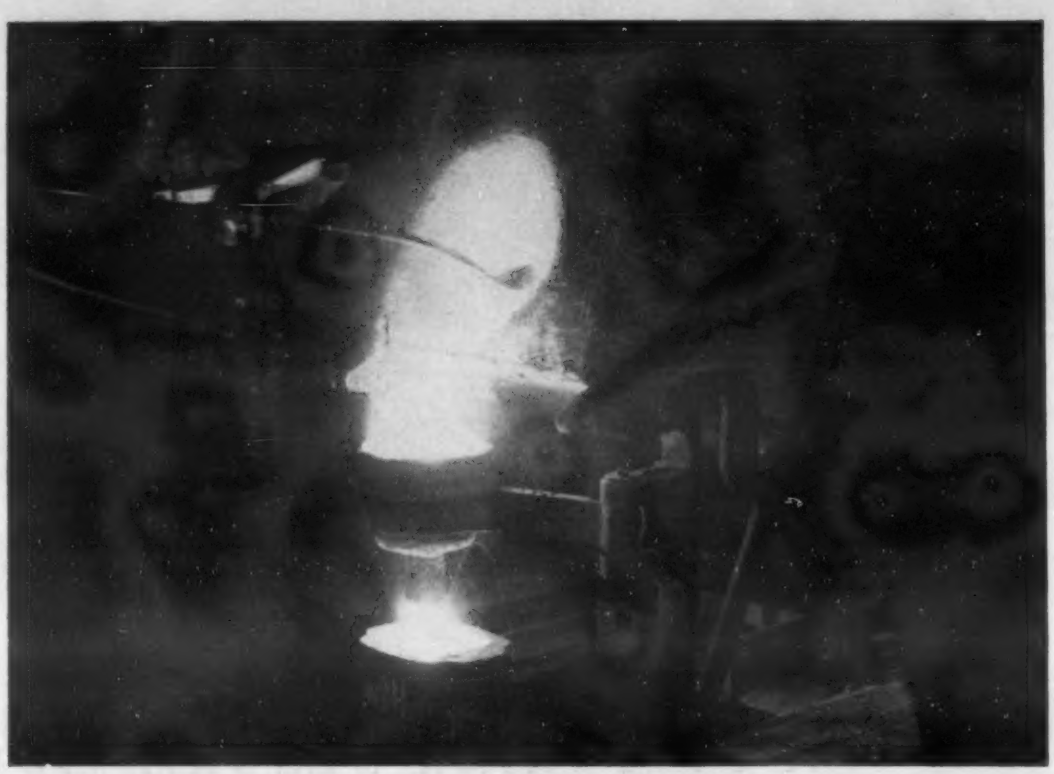
Text and Captions by Fred P. Peters,
Ass't. Editor, METALS AND ALLOYS

THIS IS THE STORY of the metallurgical product without which the electric heat that toasts our bread, brews our coffee, irons our shirts, lights our cigars, waves our lady's hair, relieves our charley-horse, and warms our feet December nights would not be the efficient, taken-for-granted thing it is today. For the practicality of modern electric heating, domestic and industrial, results directly from the high electrical resistance, excellent oxidation resistance, and workability of the nickel-chromium and nickel-chromium-iron alloys used for heating element resistors.

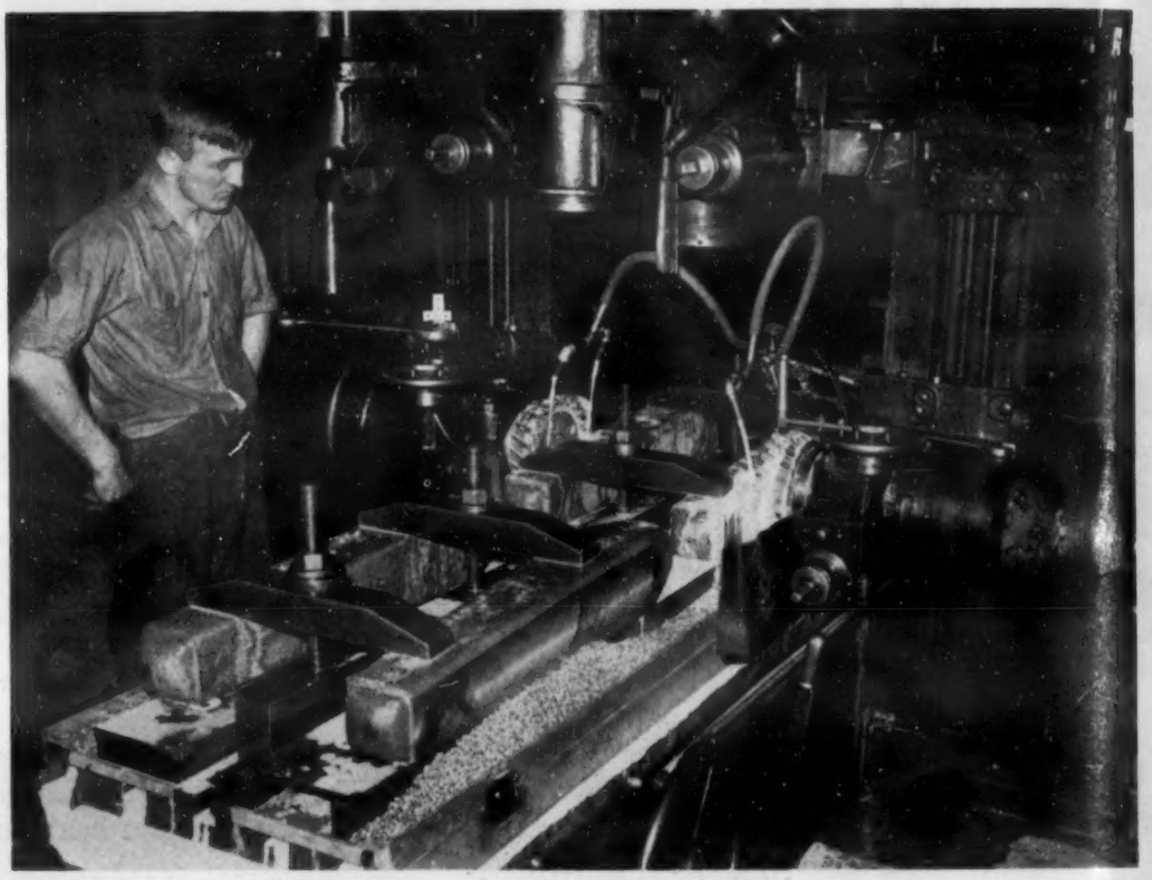
Most widely used are two alloys: One containing about 80 per cent nickel and 20 per cent chromium, and the other, slightly less durable, containing 60 per cent nickel, 16 per cent chromium, remainder iron. In America, both of these are produced and marketed under various trade names (Tophet, Chromel, Nichrome, Jelliff Alloy, Superior, Premier, etc.) by at least 5 companies (not 2, as is frequently stated). The pictures on the following pages were taken in the plant of the Wilbur B. Driver Co., and illustrate the steps in the manufacture of Tophet "A," this company's 80 Ni/20 Cr alloy.

Nickel-chromium resistance alloy presents one of the "fussiest" of metallurgical problems. Successful production of heating element wire that will have long life at high temperatures depends largely on having a clean, sound, workable ingot, of desired controlled grain size, to begin with. The melting problem is complicated by the high vapor pressure and oxidizability of chromium and the affinity of nickel for hydrogen and sulphur, both deleterious. If additions of tiny amounts of grain refiners or "protective" elements are not carefully controlled, cleanness and workability are affected; constituents added to improve workability may reduce the service life of the alloy; time and temperature must be closely watched during melting. Control of all these factors has been greatly aided through the use of high-frequency induction furnaces.

But the job is not finished with the melt, for all the production steps must be just as carefully controlled. After the ingot is poured, it is reheated, rolled in moderate passes to 1/4 in. rod, annealed, pickled, and drawn to finished size with intermediate anneals and frequent inspections. Drawing speeds and control of dies are important, annealing temperatures and atmospheres must be vigilantly maintained. When the final life-testing and inspections have been made, no wire can be shipped out that is not up to standard as to high-temperature life, electrical properties, dimensions and uniformity.



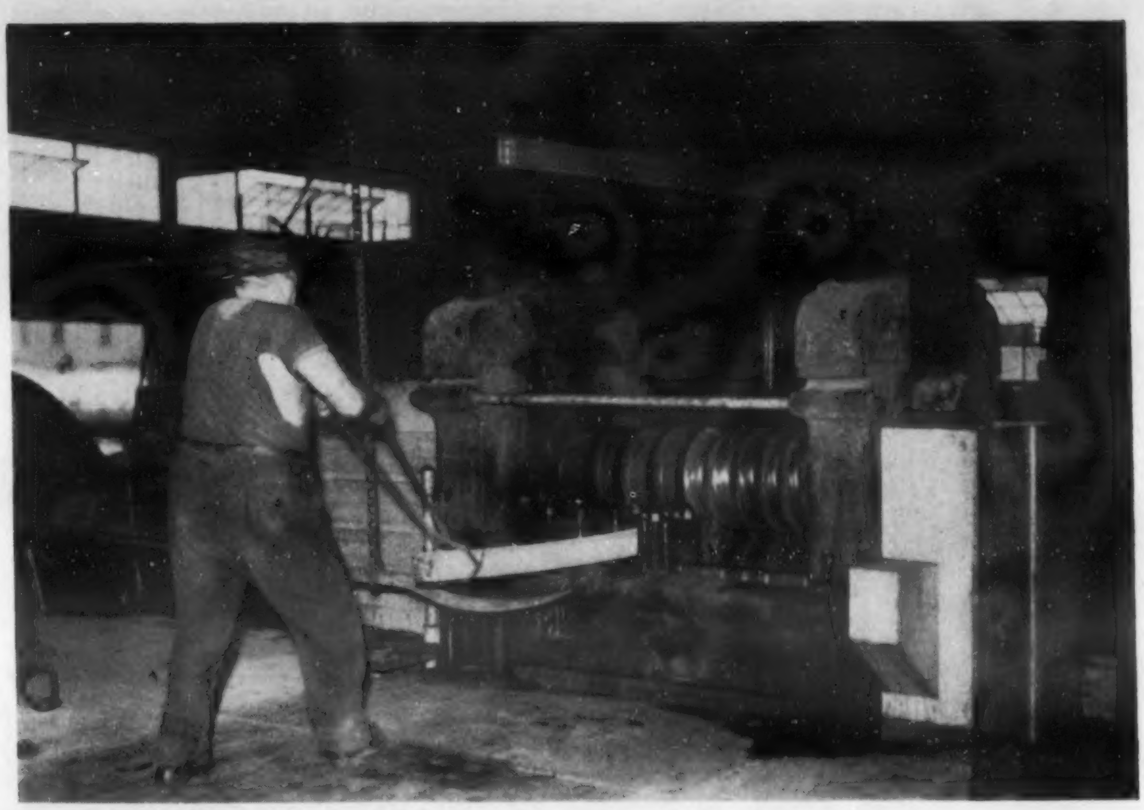
MELTING. The alloy is melted in 300-lb. lots in Ajax-Northrup coreless induction furnaces, small amounts of Si, Mn and Al are added to the Ni and Cr, and final deoxidation is accomplished with calcium silicide. The melt is poured between 2600 and 2700 deg. F.



MILLING. Later, the refractory hot top is removed, the mold is stripped and the 300-lb., 6 in. x 6 in. x 3 ft. decapitated ingot milled in the machine illustrated, to remove the casting skin.

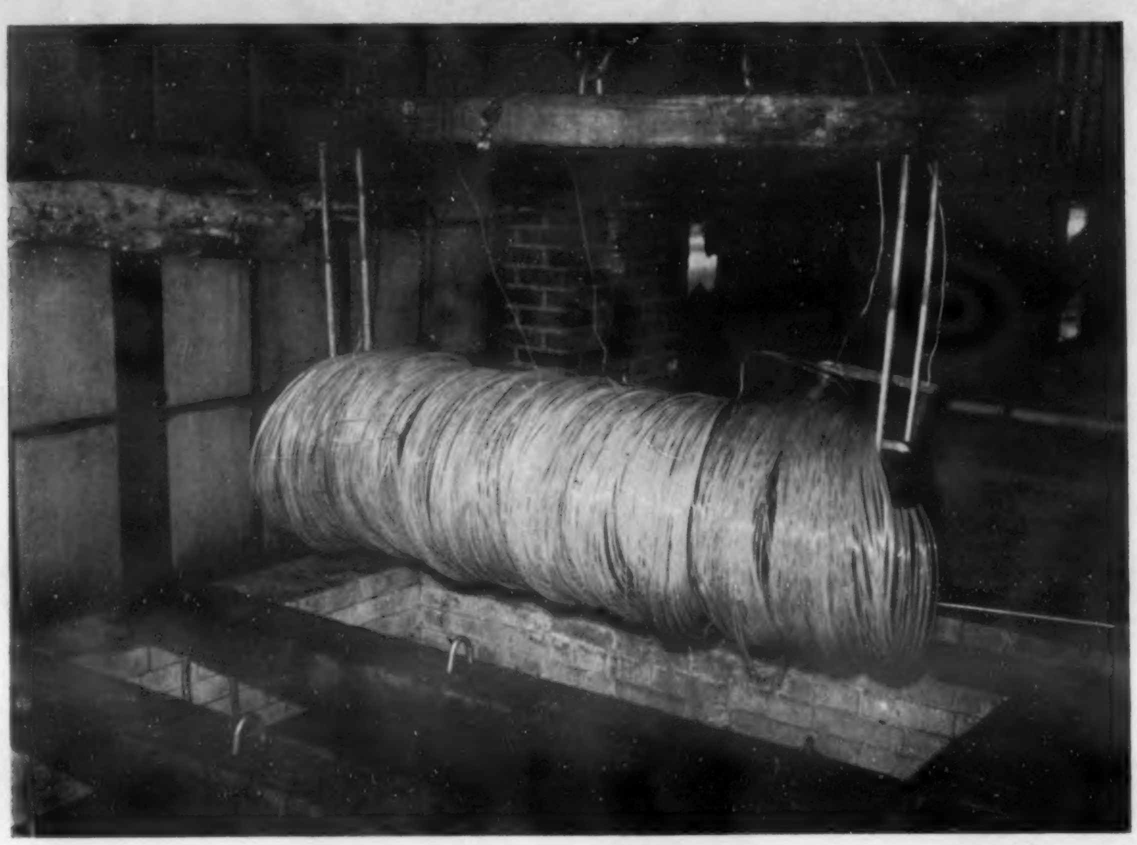
REHEATING. The bright, smooth-surfaced ingot is next heated with many others between 2200 and 2300 deg. F. for 8 hrs. in this oil-fired, automatically controlled Electric Furnace Co. unit, then transferred to the cogging mill.

COGGING. Here the ingot is passed and re-passed through successively smaller grooves between the rolls, until it emerges as a 2-in. square bar, 18 ft. long, ready to be cut into three 6-ft. lengths.



THE ROD. After the ends have been cropped, the bar is ground, chipped, reheated to 2200-2300 deg. F. and rolled in a smaller mill to 1/4 in. rod. A group of 100-lb. bundles of the rod are shown, each of which is about 530 ft. long.

SALT ANNEALING. Each bundle is next annealed at 1650-1700 deg. F. in cast heat-resistant alloy (60 Ni/15 Cr) pots containing a molten mixture of soda ash and common salt, and quenched in water. The illustration shows a coil of annealed rod being transferred from the pot to the water tank.



PICKLING. This is followed by pickling in a strong hydrochloric acid solution, an operation that is no simple matter of "dunk and rinse" with these extremely acid-resistant alloys.

HEAVY DRAWING. The heavy drafts are all made through carbide dies; lubrication is provided by previously coating the pickled rod with a special metallic lubricant; in addition, a small amount of graphite-soap powder is picked up in the diebox. The illustration shows the first drawing operation, with the 1/4 in. rod passing through the carbide die. Successive drafts through similar machines reduce the diameter of the wire to 0.114 in., when it is cleaned, reannealed, pickled, coated with lubricant and drawn on other single-hole draw benches to 0.080 in.

MEDIUM DRAWING. Continuous wire-drawing machines like that shown then take the wire from 0.080 in. to 0.036 in. These drafts are made through carbide dies immersed in circulating low-alkalinity soap solutions.

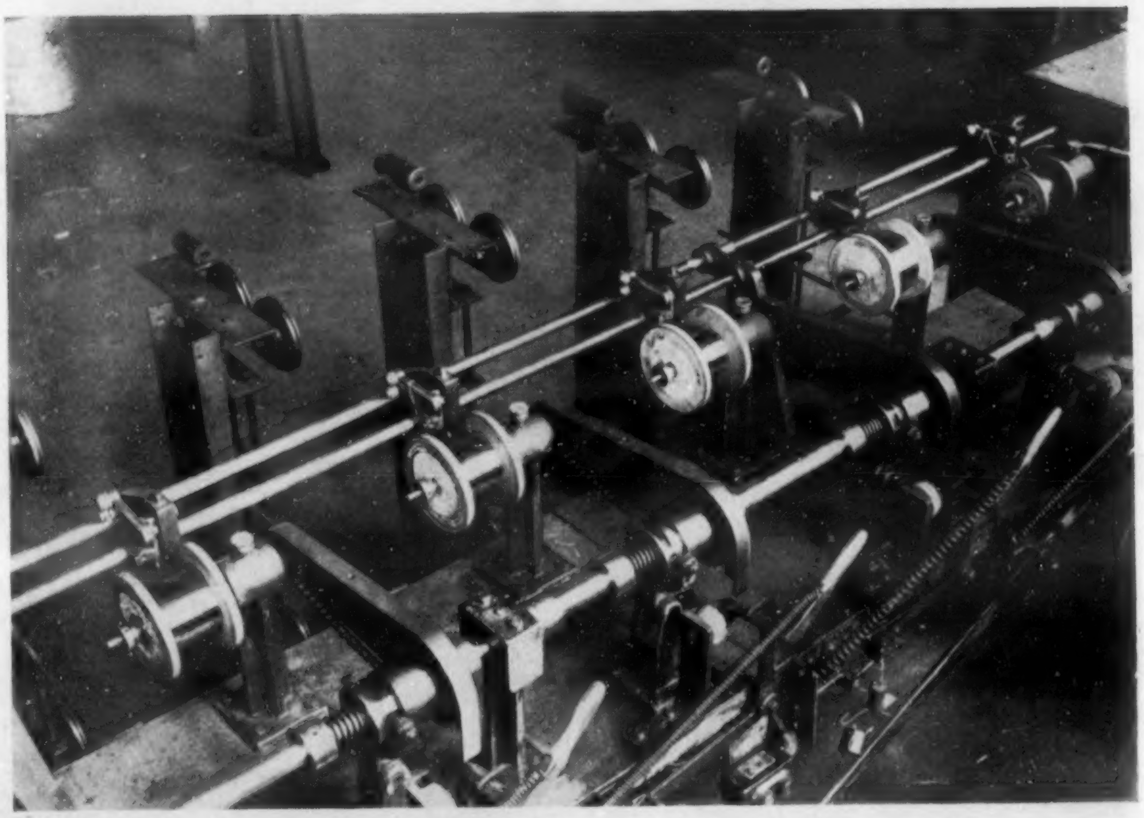
STRAND ANNEALING. After the wire is cleaned to remove the film of lubricant, it is again annealed, this time by passing it, single-strand, through the above or a similar hydrogen-atmosphere furnace at 1700-1800 deg. F. (according to size of wire, speed and amount of stock going through simultaneously). The hydrogen is previously dried by passing through an activated-alumina drying unit.

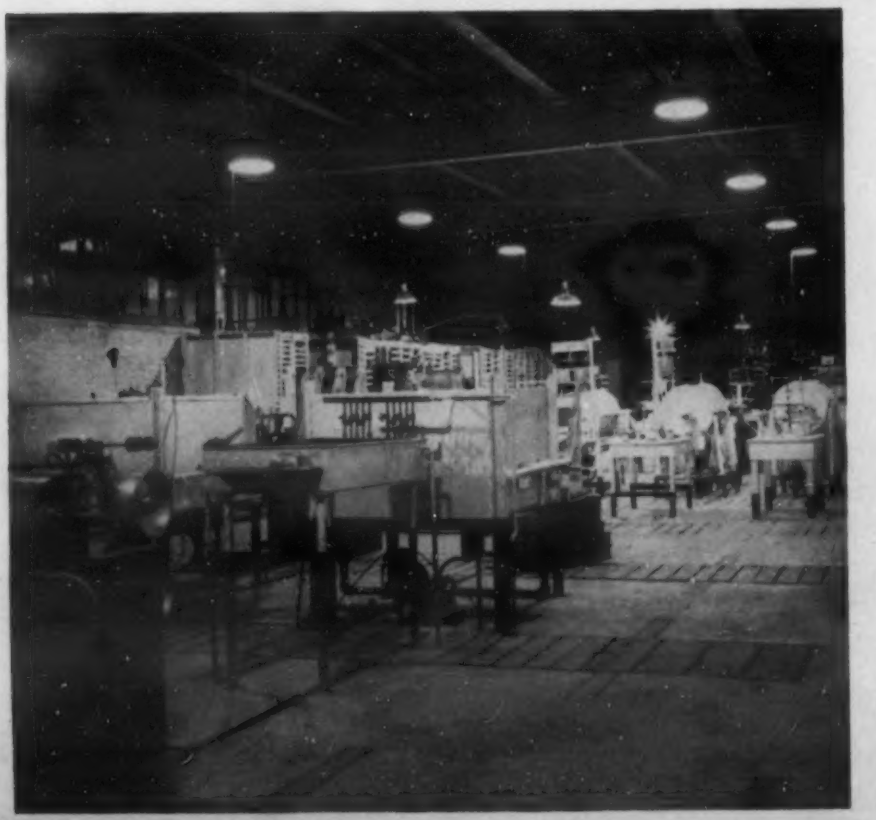
FINE DRAWING. Further reduction to "finished" size is done continuously through a line-up of diamond dies in machines like this. The lubricating solution again is of a low-alkalinity soap.

VERY FINE DRAWING. For drawing very fine wire—as fine, in some cases, as 0.0008 in. or less than 1/3 the diameter of a human hair—wire drawing machines of this type are employed.

FINISH ANNEALING. The wire, drawn to correct size within ±0.0002 in., is cleaned of soap film and passed through one of the hydrogen-atmosphere annealing furnaces at 1600 to 1900 deg. F. (depending on wire size) shown here. Part of the temperature control panel can be seen in the background.

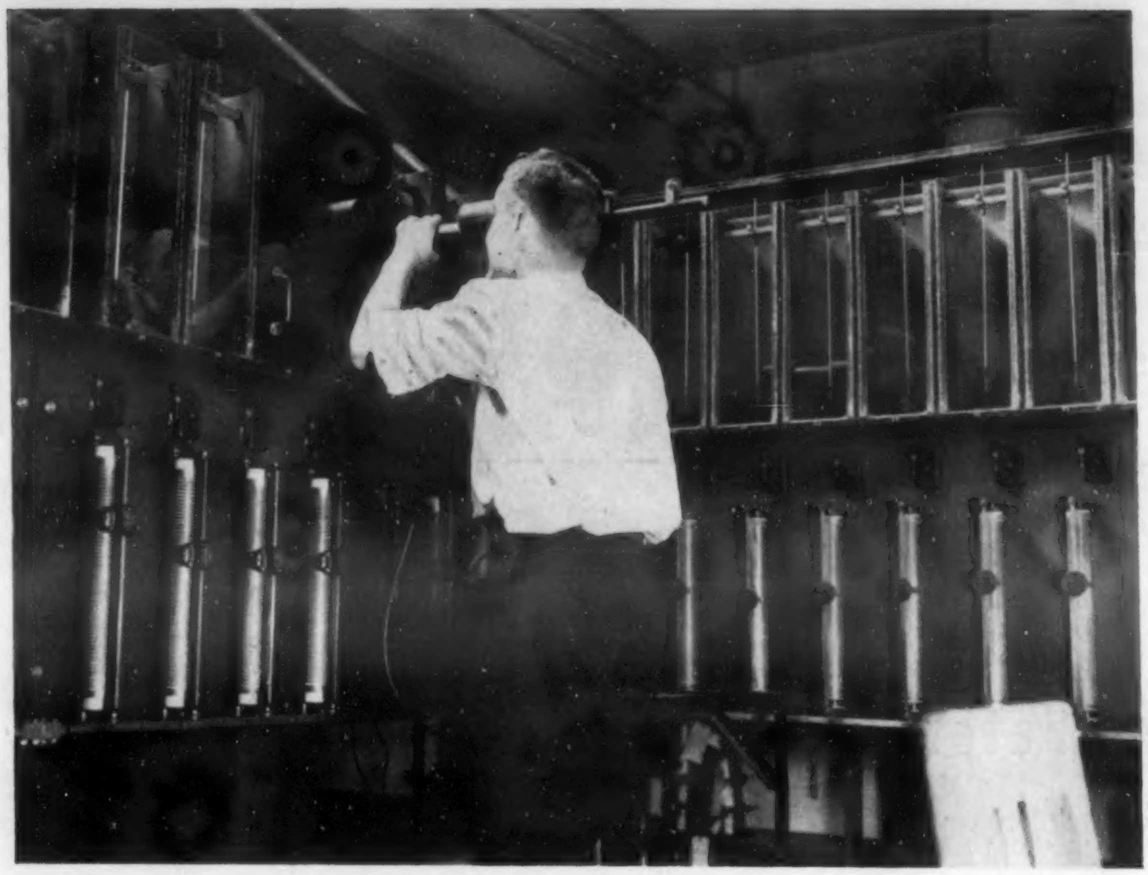
RESPOOLING. The final neat, compact, even-layered spooling is done on machines like this. Successive turns of wire on each spool must be laid down without "crossing," for crossed wire causes tangling when the wire is later run off the spool in the customer's plant.

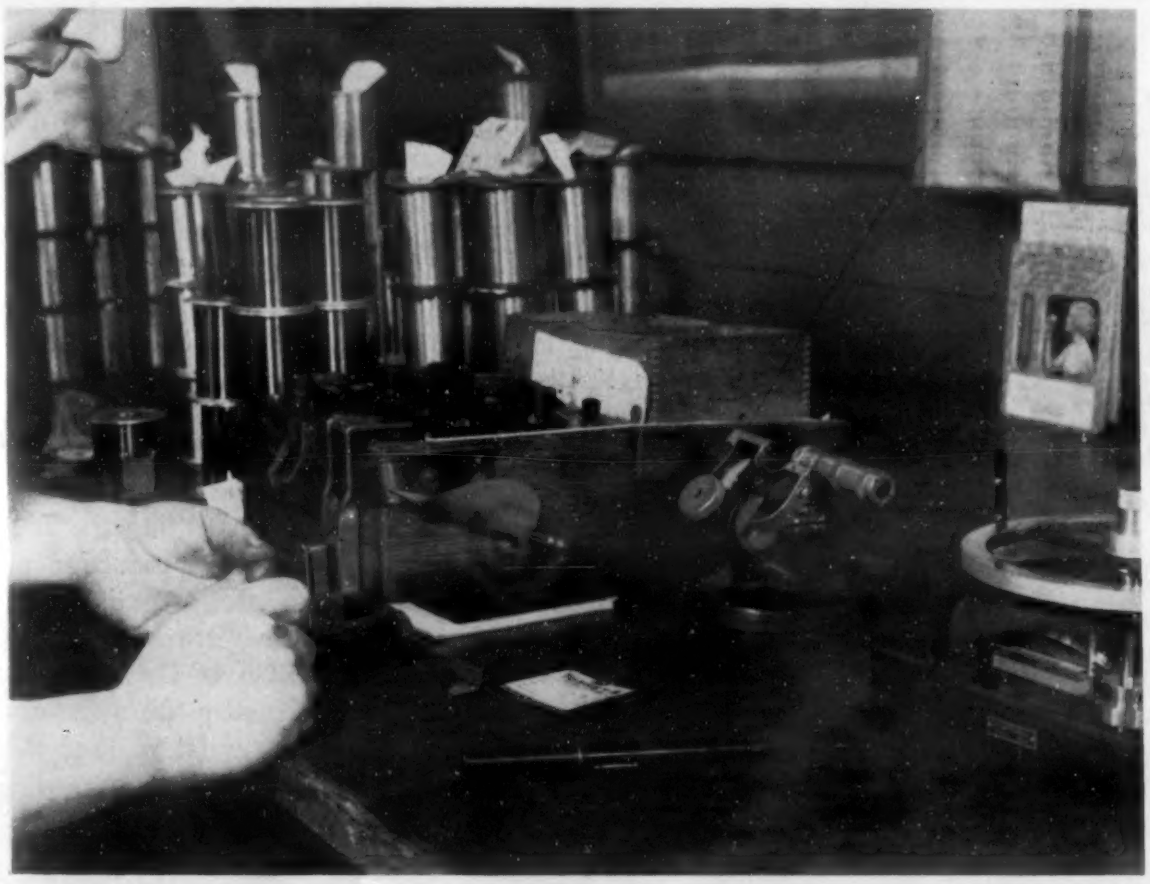




COMBINATION ANNEALING AND SPOOLING. The most advanced finish-annealing practice is exemplified by the furnace in this picture. Wire passing through it is spooled directly on the machine at the left, no subsequent transfer respooling being necessary.

LIFE TESTING. Each lot of heater wire is subjected to the standard A.S.T.M. high temperature life test, in which a stressed specimen is electrically heated, in a glass-enclosed compartment, in 2-min. off and 2-min. on cycles until burn-out occurs. This photo shows a testing engineer reading the wire temperature with an optical pyrometer.





INSPECTION. In the inspection department the electrical resistance and diameter of the wire on each spool are accurately measured and recorded on the label affixed to the spool. Resistance of very fine wire is measured with a Wheatstone bridge, and of heavier (lower resistance) wire with a Kelvin bridge for greater accuracy. Diameter and "roundness" are checked with a Zeiss indicating micrometer or the latest type of "light-wave" micrometer, both of which can be seen in this picture.

READY FOR USE. The large spool shown here holds about 5 lbs. of 0.020 in. wire, the small spools about 2 lbs. of 0.010 in., each. The original 300-lb. ingot was 3 ft. long; at 0.003 in., the size of wire used in many very small units, the length of wire drawn from the original ingot would be about 2000 miles.

In addition to its familiar application as domestic appliance heater wire, nickel-chromium alloy is widely used industrially: Bar stock for furnace parts; rod and heavy wire for furnace resistors; medium-size wire for rheostats and, in the chemical industry, for dipping baskets and filter cloth; and fine wire for electronic tube grids, instrument resistances, and many other applications.

The Hydride Process—IV

—COMMERCIAL PRODUCTION OF URANIUM

by Peter P. Alexander

General Manager,
Metal Hydrides, Inc., Clifton, Mass.

Commercially pure uranium is assured by the author if the Hydride Process is employed. Some interesting alloys of uranium, possibly of commercial importance, are also forecast. Of particular interest is a master alloy of U and Ni, containing 66 per cent U. He compares the present methods of securing metallic uranium with his. This is the fourth article in a series on The Hydride Process. Part I, the first published presentation of this new and important development, appeared in *Metals and Alloys*, Vol. 8, Sept. 1937, page 263. Part II was published in Vol. 9, Feb. 1938, page 45 and dealt with the preparation and properties of titanium hydride and the production of Cu-Ti alloys. Part III was published in Vol. 9, July 1938, page 179, and discussed titanium silicides.

URANIUM, IN SMALL QUANTITIES, is found in the composition of a number of minerals which have been reported as occurring in many states in the United States, and in a number of other countries. Yet the percentage of uranium in these rather rare minerals is so small that at present these small deposits have only a scientific interest.

Minerals Supplies of Uranium

Only two minerals, namely Carnotite (approximate composition $K_2O.2UO_3.V_2O_5.3H_2O$), and Pitchblende, an impure uranium oxide of the formula U_3O_8, are found in sufficently large quantities to have commercial value at present.

The most important uranium ore deposits in the order of their discovery, are:—

1. The Pitchblende deposits in Czechoslovakia.
2. The Carnotite deposits of the Utah-Colorado area.
3. The Pitchblende deposits in the Belgian Congo.
4. The recently discovered deposits of Pitchblende in Canada.

The Joachimsthal deposits of pitchblende in Czechoslovakia which have been worked for uranium and radium since 1905, at first supplied all the demand for these two metals. Yet with the increased demand for radium, the Utah-Colorado deposits of carnotite assumed such importance that between the years 1913 and 1922, most of the world supply of radium, and consequently uranium, was furnished by the United States from domestic carnotite ore.

But when, in 1922, the richer and larger deposits of pitchblende in the Belgian Congo became productive the exploitation of the United States ores temporarily became less important. Up to 1930, the Belgian Congo supplied practically the total amount of uranium and radium for the world market. Yet since the discovery in 1930, of rich pitchblende deposits at Great Bear Lake in Canada, the situation has changed, and the increasing supplies of Canadian pitchblende are supplementing the Belgian Congo supply of this ore. Also the production of uranium salts from the domestic deposits of carnotite again became active. At the present time the Vitro Mfg. Co. of Pittsburgh, and the Shattuck Chemical Co. of Denver, Col., produce uranium compounds in this country, from the domestic carnotite ore. However, a substantial part of the domestic requirements is still satisfied by imports from the Belgian Congo and partly from Canada. In 1936, for instance, the imports of Belgian uranium salts reached 341,040 lbs. The imports of the Canadian product into the United States during 1936 rose to 62,567 lbs.

The present rate of production of uranium oxide at the Port Hope refinery in Canada has reached 35,000 lbs. per month, and it is stated that the known deposits at Great Bear Lake are sufficient to maintain this rate of production for ten years. It may be expected, therefore, that the importation of Canadian Uranium Oxide into the United States will be increasing.

Extraction

Klaproth and the early workers treated pitchblende ore for the extraction of uranium only, and their methods consisted essentially in the digestion of powdered ore with nitric acid, and the extraction of soluble compounds with water. The uranium oxide was obtained after a series of operations, as an insoluble residue.

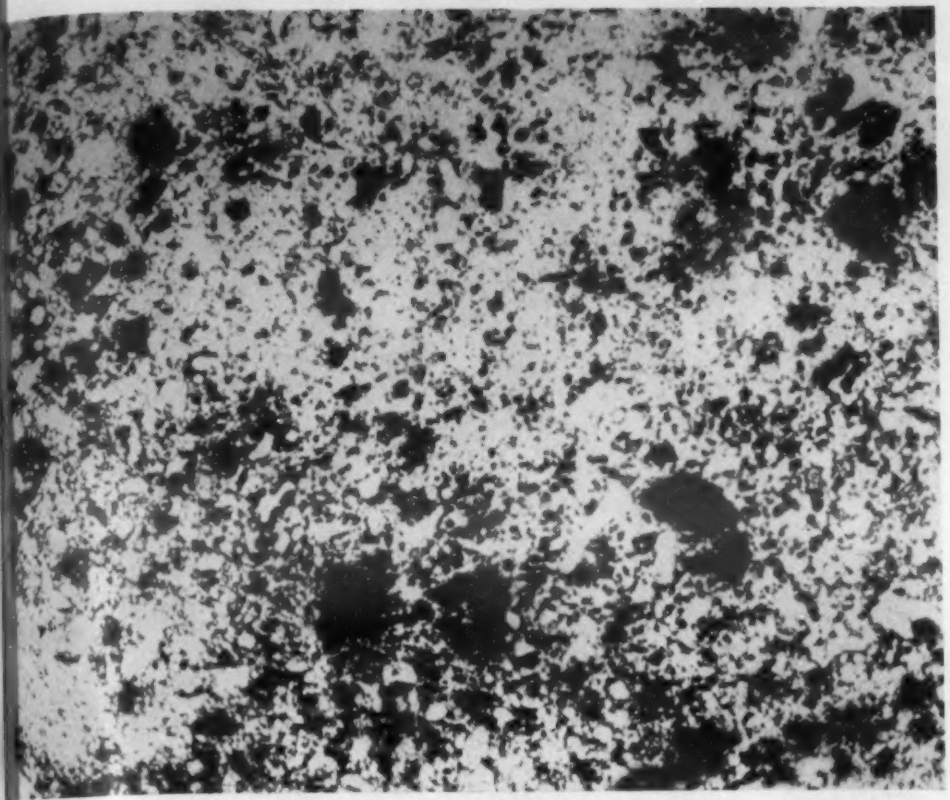


Fig. 1. Sintered Uranium Metal. 100 X. Etchant: 10 per cent oxalic acid electrolytic. Dark areas are voids in the specimen.

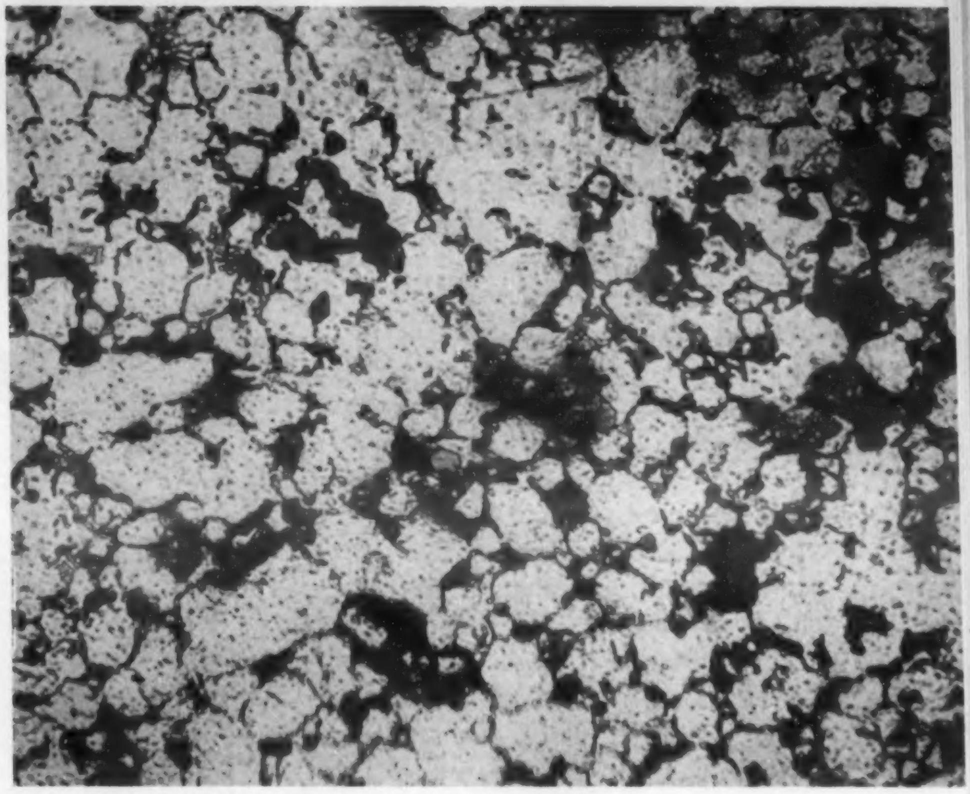


Fig. 2. Same as Fig. 1. 500 X.

At the present time the main purpose of treating uranium ores is to extract the radium, and uranium salts are produced as a by-product. The important step, therefore, is the separation of these two elements. The roasted and milled ore is treated with sulphuric acid which produces water-soluble uranium sulphate, and insoluble radium salts. A following treatment with hot water takes up into solution all the uranium, and leaves as insoluble residue, the radium salts.

The filtrate containing uranium is pumped out and treated with various reagents to precipitate iron, aluminum, nickel, cobalt, etc. Finally the purified solution of uranium salt is treated with ammonia which precipitates the yellow uranium hydrate. The calcination of the hydrate finally gives pure anhydrous uranium oxide. The uranium oxide, which is now a starting point in the production of uranium metal, is therefore of high purity, containing only a very small amount of other metals.

Metallic Uranium

The preparation of uranium metal in the pure state is an extremely difficult problem. This element has such a great affinity for most of the substances with which it comes in contact during the reduction and fusion operations, that it is very difficult to prepare it in large quantities without contamination either with oxygen, nitrogen and carbon, or such metals as iron, nickel, etc.

Fig. 3. Fused Uranium Metal. 100 X. Etchant: 10 per cent oxalic acid electrolytic.

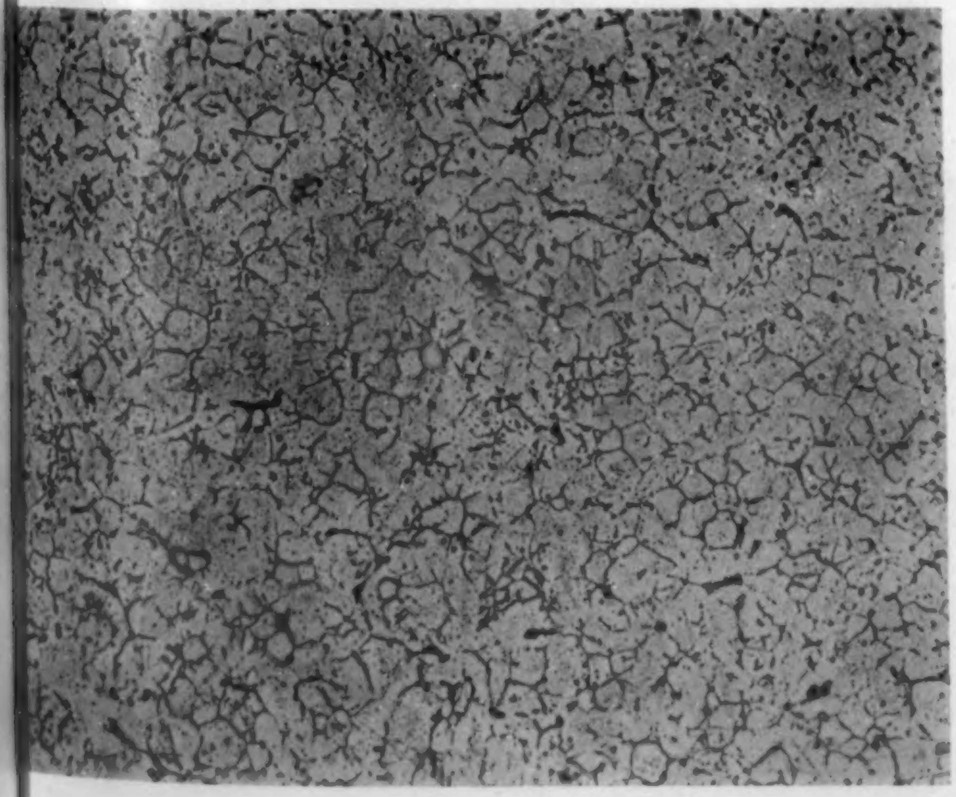
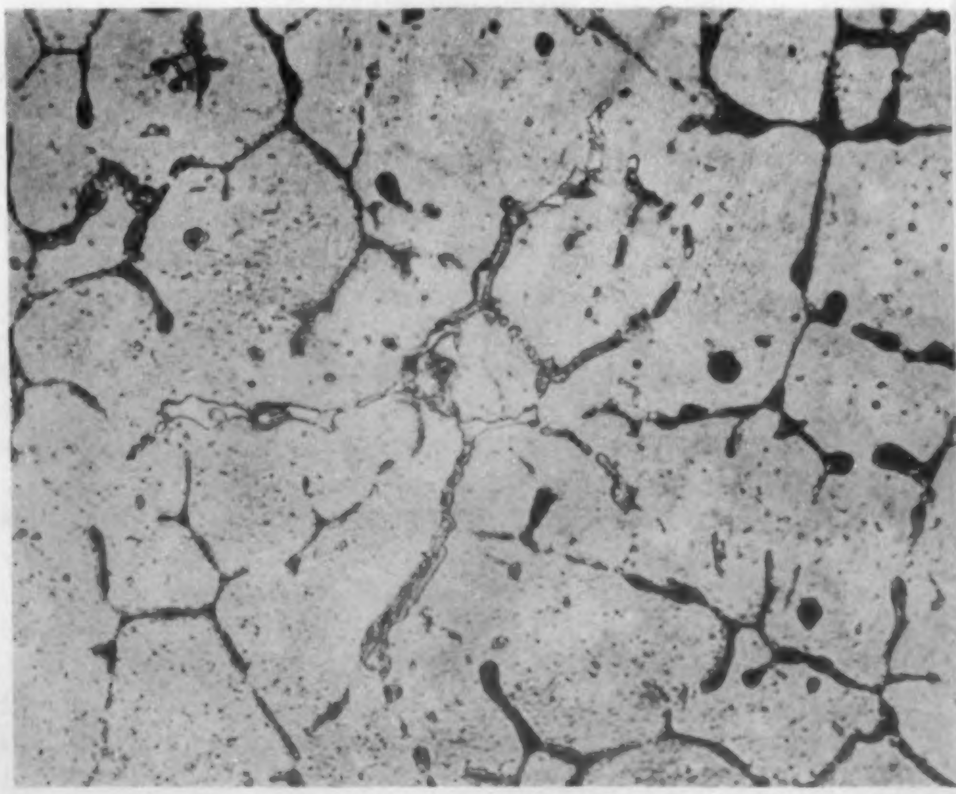


Fig. 4. Same as Fig. 3. 500 X.



The excellent work done by such painstaking investigators as A. Burger, E. A. Redeal, R. W. Moore, Gurtler and Pirani, and J. W. Marden and H. C. Reutschler, resulted in the production of small quantities of uranium of high purity and gave considerable information on the properties of this element. Yet their work also indicated, that, in spite of the most refined laboratory technic, available only in modern research laboratories, the danger of contamination of the produced metal, especially with oxygen, is so great that one can hardly expect the data obtained by different investigators to be even approximately the same.

In consequence, one of the most important data with regard to uranium, namely its melting point, is still unknown, and the International Critical Tables, for instance, simply record that it is lower than 1850 deg. C. But how much lower, is not definitely established as yet. The published figures vary from 1850 down to 1300 deg. C., and the indications are that it might be still lower.

The same uncertainty prevails with respect to other important properties of uranium, such as its electrical conductivity, hardness, ductility, etc.

As stated, uranium is an extremely active element and readily combines with oxygen, nitrogen and carbon, forming very stable compounds of very high melting points, in the order of 2200-2500 deg. C. It is also readily dissolved by all acids and is acted upon even by warm water. Powdered uranium ignites in air at about 170 deg. C.

Laboratory Methods of Preparation

The laboratory methods of preparation of small samples, in the order of a few grams, usually consist in the reduction of either the chloride or oxide of uranium with sodium, or with metallic calcium.

The resulting uranium metal comes in the form of fine powder mixed with the products of the reaction which must be leached out from the powdered mixture with dilute acids, and the powder dried in vacuum. This leaching inevitably oxidizes more or less the particles of the produced uranium, so that the resulting powder is either black or brown. The true color of massive unoxidized uranium is that of polished steel.

The purest uranium (99.8%) was produced by R. W. Moore.[1] This investigator worked with very small quantities of re-distilled uranium tetrachloride which was reduced in special laboratory apparatus with re-distilled sodium. The produced brown powder was then pressed into small buttons and fused by electric arc in an argon-filled glass bulb used in laboratories as a furnace for such precise work. The produced metal was found to be quite ductile, and the ingot was rolled into thin sheets, only 15 mils thick.

This method of production of uranium can be carried out only in the laboratory, since the preparation of anhydrous uranium chloride is in itself an extremely difficult operation. The handling of metallic sodium or fusion by the electric arc in pure argon, requires great skill and can hardly be attempted on a factory scale.

A more practical method was used by J. W. Marden and H. C. Reutschler,[2] who perfected the technic of the earlier investigators in the reduction of uranium oxide with metallic calcium in steel bombs, lined up with layers of pure calcium oxide.

Their method consisted essentially in mixing a charge of a few hundred grams of pure uranium oxide with chips of metallic calcium and sodium chloride, closing the top of the bomb with a steel cover bolted to the bomb, and heating the whole in the furnace to the temperature of bright red heat. At a certain temperature the reaction started and was proceeding to completion with the generation of a considerable amount of heat. In other words, this method is a modification of the Thermit process with all the advantages as well as the limitations of that process.

The uranium obtained by this method is also of high

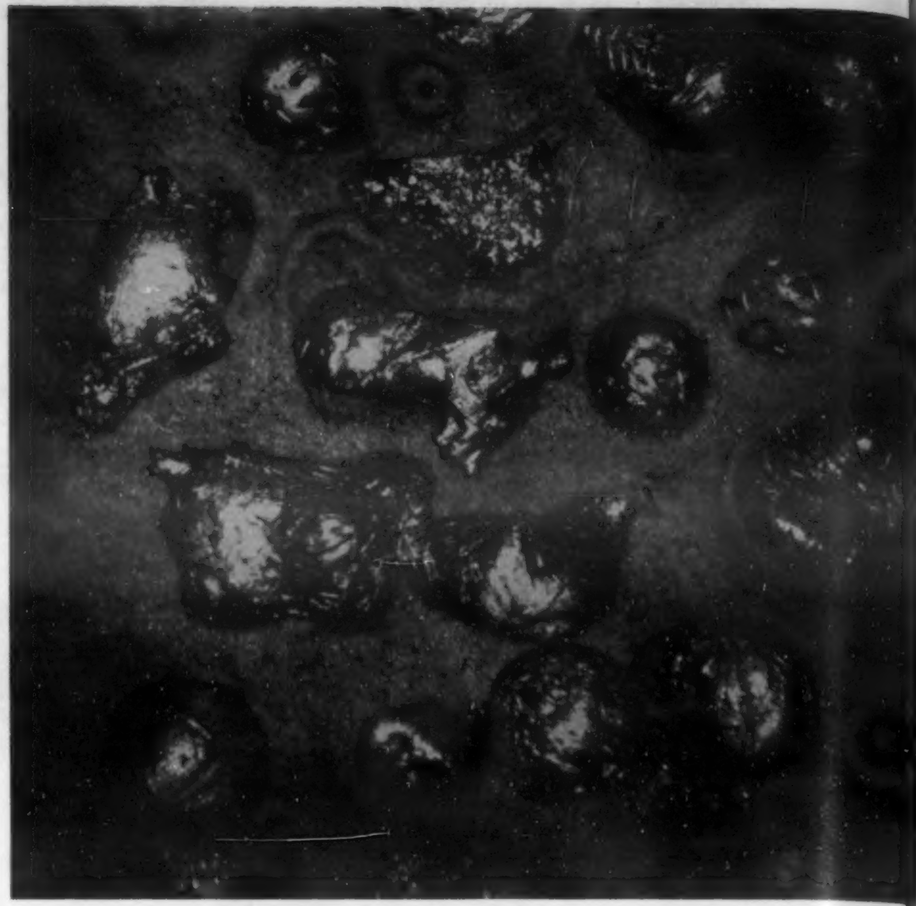


Fig. 5. Round Pellets of Uranium—Nickel Alloy (U = 66%). N… metallographic preparation. 10 X.

Fig. 6. Flat Surface of One of the Pellets. Oblique illuminati… 30 X.

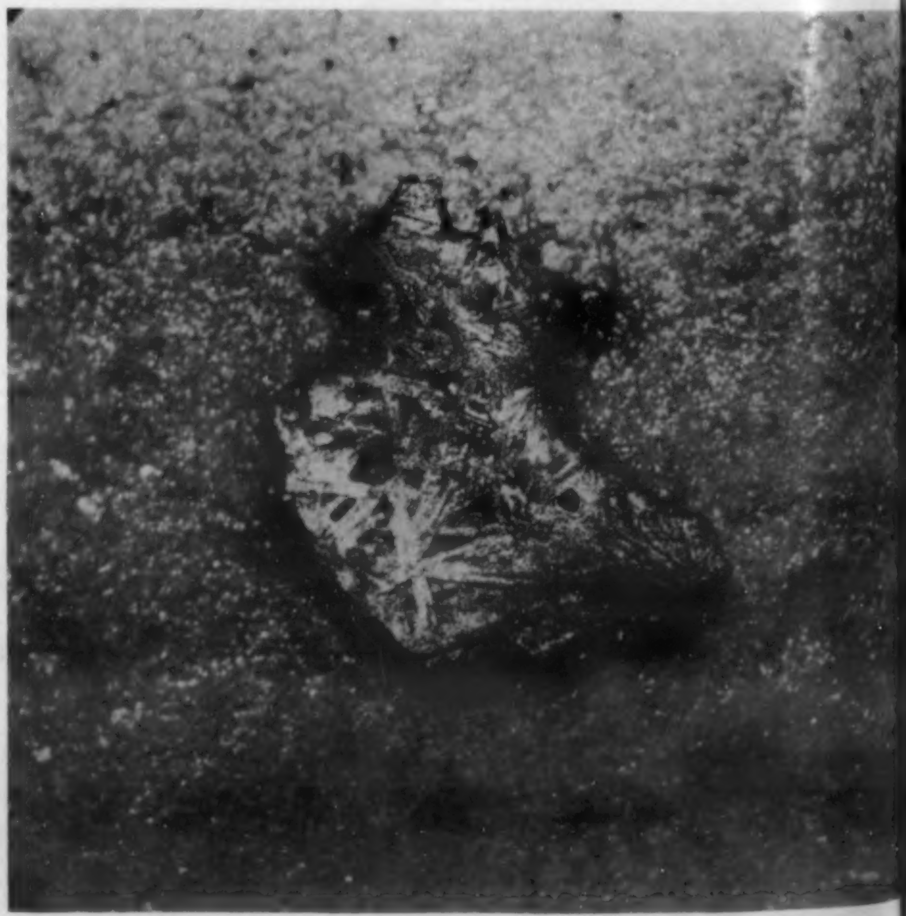


Fig. 7. Uranium-Nickel Fused Alloy ($U = 66\%$) Cooled slowly in the Furnace. Polished Section. Etchant: Merica's reagent followed by ferric chloride. 100 X.

purity and comes in the form of powder which must be leached from calcium oxide and calcium chloride with dilute acid, and consequently is slightly oxidized. However, with the refining of the technic of various operations, the above investigators probably could produce uranium of about the same purity as that prepared by Moore, and which is quite suitable for the production of various devices which must be prepared from high purity uranium powder.

The Hydride Process of Production of Uranium

ALTHOUGH the described methods undoubtedly give excellent results, and supply the demand for uranium of very high purity for scientific investigations and the production of special devices, it was thought that even a somewhat less pure metal of about 98 per cent purity, could find considerable application if such a product could be made by a simpler method which could be carried out on a larger scale under factory conditions and, therefore, at a lower cost.

In developing the technic of the production of uranium by the Hydride Process, it was kept in mind that the produced material should be of a quality suitable for handling on a comparatively large scale, that it should be of sufficient purity, in the order of 98 per cent, and that it should not be pyrophoric, which is often the case with very pure fine powdered uranium, so as to be reasonably safe for handling in dry state without danger of spontaneous combustion.

Furthermore, since a large part of the produced uranium would eventually be used in the production of special alloys, a suitable master alloy of uranium with some suitable base metal, should be developed, which could be used as an addition to the ladle. It is believed that these aims have been accomplished by methods which will be described below.

Briefly, the present practice adopted by Metal Hydrides, Inc.,[3] consists in the following operations:

The calcined uranium oxide and powdered calcium hydride are weighed and loaded into a steel tumbling barrel where they are mixed for about half an hour. Then the mixture is loaded into open steel containers, each holding about 20 lbs. of the charge. The containers are then placed in a hydrogen furnace of a special type where the charge is heated to about 980° C.

At that temperature the calcium hydride gradually dissociates into nascent hydrogen and nascent calcium which, in such a state, are much more reactive than when these elements are merely in a state of high purity but otherwise stable. The reaction proceeds gradually and the temperature of the charge never rises above that of the furnace. In fact, it is constantly under control, and by decreasing or increasing the temperature of the furnace, can be either accelerated or retarded.

After cooling, the resulting material is loaded into a 200-gal. tank provided with a mechanical agitator, where it is leached from all calcium oxide. The powdered uranium is then sluiced into a filter press where it is washed and partly dehydrated. The final drying is carried out in vacuum ovens.

The Uranium Produced

The produced uranium comes as a fine brownish powder of 150-300 mesh. The average analysis is:

	Per Cent
Uranium	98.0
Iron	1.0
Silicon	Trace
Aluminum	"
Calcium	"
O_2, N_2, H_2	Balance

This brownish color is due to a very thin film of oxide which is produced during the leaching operation on the surface of the individual grains. The film is so thin that it does not alter the composition of the produced metal. Yet it is quite necessary to protect the metal from rapid oxidation and eliminate the danger of spontaneous combustion. The produced powdered metal, therefore, can be handled in air and pressed under hydraulic press into briquettes with 100 tons pressure per square in. Then it is sintered at a temperature of 1000 deg. C., in an atmosphere of pure hydrogen evolving from some suitable metallic hydride, such as zirconium hydride.

The same material can be fused in a vacuum of less than six microns at the temperature of 1250 to 1300 deg. C. It is curious to note that the fused uranium requires a much higher temperature if it is to be refused a second time. This can be explained by the fact that during the fusion, molten uranium absorbs traces of oxygen which are present in the furnace even when the greatest precautions are taken to eliminate them. The fused uranium also combines with the refractories, reducing them and absorbing a certain amount of oxygen. Although it is more than likely that the melting temperature of 100 per cent pure uranium is not higher than 1200 deg. C., yet when the metal is contaminated with UO_2, which melts at about 2500 deg. C., the melting point of impure uranium rises rapidly.

The density of uranium fused in a vacuum of less than six microns has been found to vary slightly in the different samples. The highest value observed was 21.3. This figure probably is of the purest uranium produced.

Contamination with UO_2, which has the density of 10.5, undoubtedly reduces the density of uranium. The density of pressed and sintered uranium powder varies from 16.1 to 18 in accordance with the length of time of sintering.

Acid Resisting Uranium Alloys

SINCE it has been realized that by far the larger tonnage of uranium will be used in the production of special alloys, a series of alloys of uranium with different metals, were produced, to determine their respective values as master alloys, which could be used as addition to the ladle.

Uranium Master Alloy—U-Ni

One of the surprising features of this work was the discovery of a binary alloy of uranium and nickel containing 66 per cent of uranium. This alloy is produced in the form of a powder consisting of grains varying in size, and fused pellets of silver-like hard alloy, varying in size from 20 to 60 mesh.

This coarse powder can be fused at 1200 deg C. into ingots which have a density equal to 14. It is hard, brittle, non-magnetic, and can be easily ground into fine powder. The photomicrographs of uranium and uranium-nickel alloy prepared for the author by R. F. Bailey of the River Works Laboratory of the General Electric Co., to whom thanks are here expressed, give the structure of the alloy in a state of powder, sintered and in a fused state.

The most notable quality of this alloy is its remarkable resistance to acids, including aqua regia. In fact, when this alloy had to be dissolved for chemical analysis, it was necessary to boil the powdered alloy in aqua regia for a considerable time. When heated for short time even in powdered state to red heat, it is only slightly changed in its silver-like appearance, by acquiring an extremely thin layer of oxide. Under the microscope, the grains and globules still reveal the same silver-like appearance as before calcination. This is quite an astonishing property, since a number of uranium-nickel alloys of other composition are pyrophoric, and ignite spontaneously when exposed to the air even at room temperatures.

The high percentage of uranium in the "66" alloy, the low melting point and resistance to oxidation, and the high density make this alloy a very suitable material for addition to the ladle. Indeed, when this alloy is added to the ladle of molten steel, nickel or copper, it rapidly sinks and alloys with the bath without excessive oxidation and loss of expensive uranium. Furthermore, its unexpected resistance to acids indicates that uranium-nickel alloys, with or without the addition of other elements, may constitute a new series of corrosion resisting materials.

The uranium-nickel alloys of composition approaching that of alloy "66" have similar properties. In fact, the final composition of the master alloy which will be most suitable for the production of various special alloys will probably be somewhat different to that of alloy "66."

References

[1] *Trans. Am. Electrochem. Soc.*, Vol. 43, 1923, page 317.
[2] *Z. anorg. allgem. Chem.*, Vol. 138, 1924, page 321.
[3] U. S. Patent No. 2,038,402, 1936.

THE METALLURGICAL STORY OF THE

Ford Centrifugally Cast Steel Gears

by Edwin F. Cone

ANOTHER INNOVATION in the production of special parts for Ford automobiles has been achieved by the metallurgical engineers of the Ford Motor Co. It is the casting of steel gear blanks by the centrifugal process—for the cluster transmission gears and the rear axle gears. The metallurgical story of this development is highly interesting.

Not many years ago Henry Ford told his engineers that it was a cardinal principle of his that whenever it was possible to produce an automobile part so that about 25 per cent or more metal could be dispensed with, such a process should be developed. If a product consumed 100 lbs. of metal by the conventional method and it could be found possible to turn it out by a modified or new process with a saving of 25 lbs. or so of metal, that should be the aim and policy—without of course any deterioration in quality.

It is this general principle which has been back of the numerous rather startling Ford metallurgical processes which have come to light from time to time. For past demonstrations of the success of this policy witness the Ford cast steel crankshaft,[1] the Ford cast steel piston,[2] and some other products. In the case of the cast crankshaft,

Pouring Centrifugally Cast Steel Ring Gear Blanks in Initial Experimental Outfit.

Removing a Centrifugally Cast Steel Gear Blank from the Casting Machine.

marked savings in metal required and in machining involved were achieved—a forging was replaced by a casting.

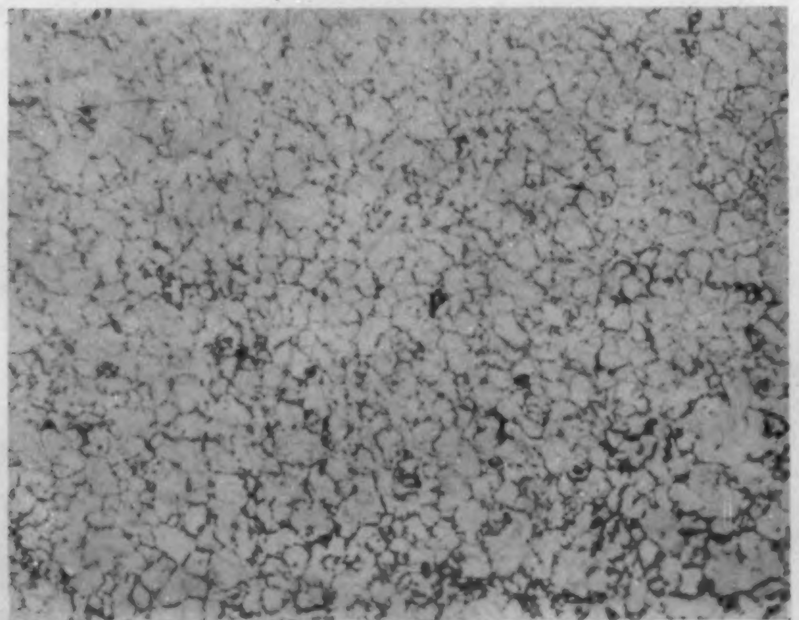
In the present case—transmission and axle gear blanks—the same principle has been applied and centrifugal castings are being made commercially to replace forgings. It has taken over a year of experimental research work to develop this process. While these gears are being made commercially today, there are still a number of problems to solve so that the process in its present stage will still be modified and improved. But the facts to date are of general metallurgical interest.

Centrifugal Casting Not New

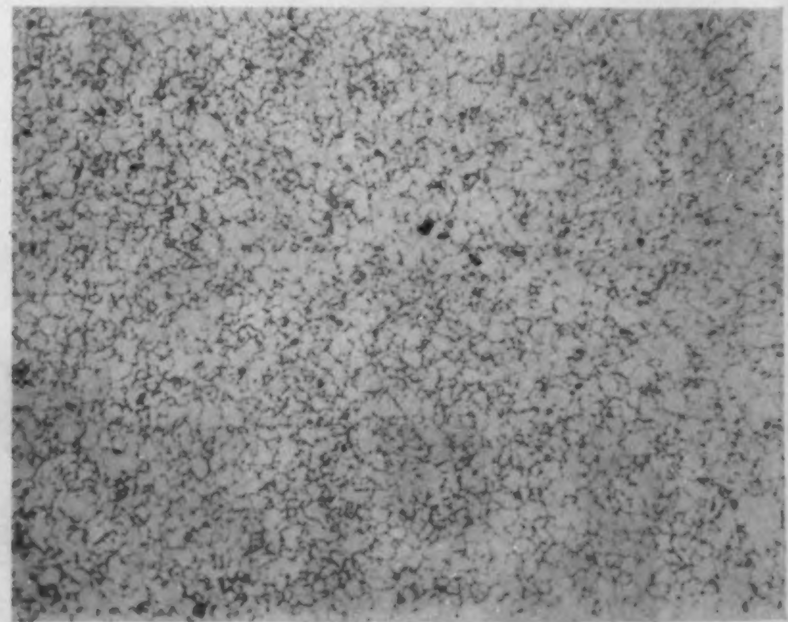
Centrifugal casting of various products from metals and alloys, ferrous or non-ferrous, is by no means new. Several years ago there was more than one instance where various products were cast in a rapidly revolving mold, usually of metal. Many of these are today established commercial processes.

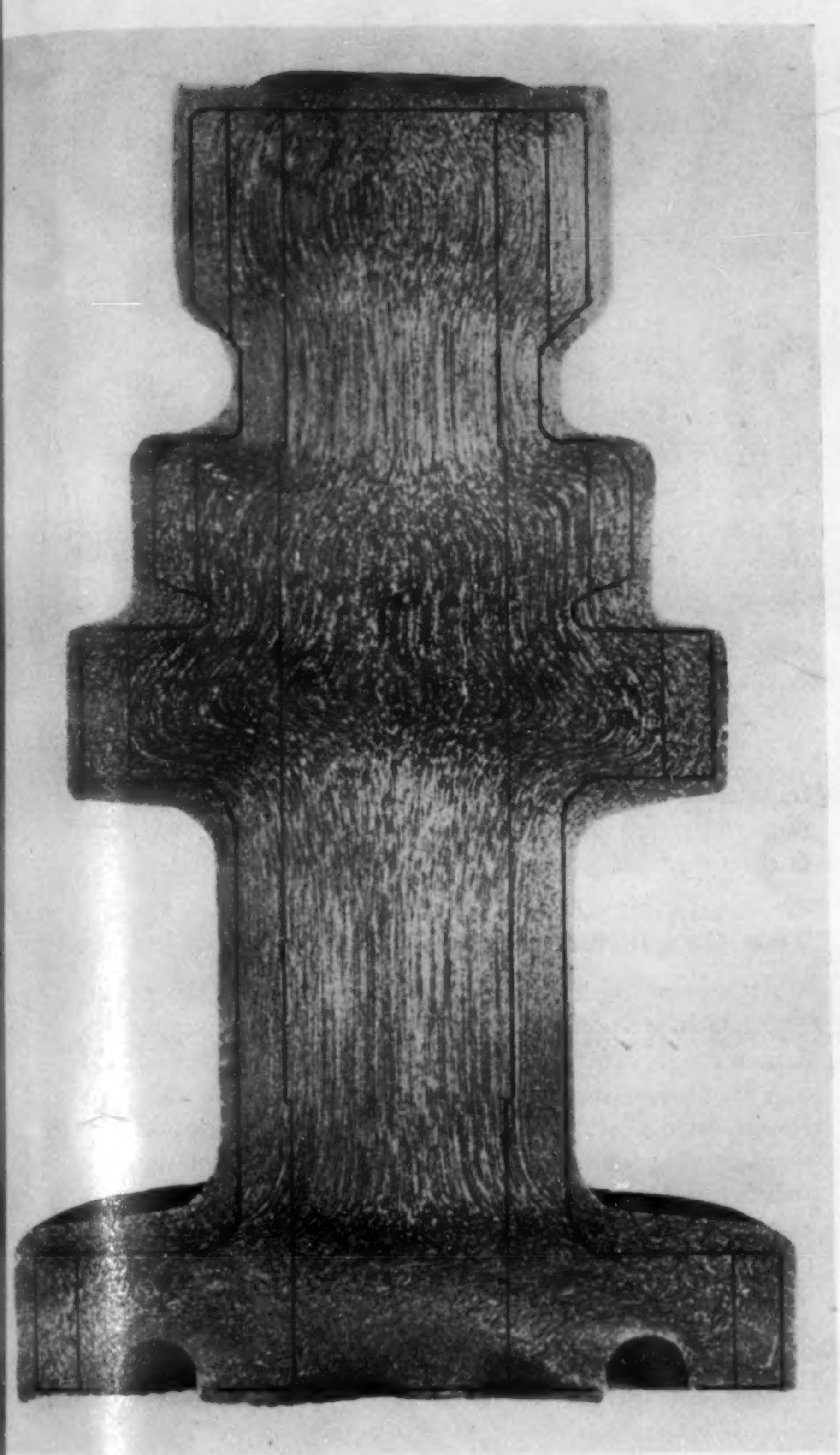
One of these of outstanding prominence is the centrifugal casting of cast iron pipe. Some 20 or more years ago, the writer had the rather unique experience of being shown a

Microstructure of the Centrifugally Cast Steel Cluster Gear Blank in the As-Cast Condition. Grain refinement is a feature. X 100.

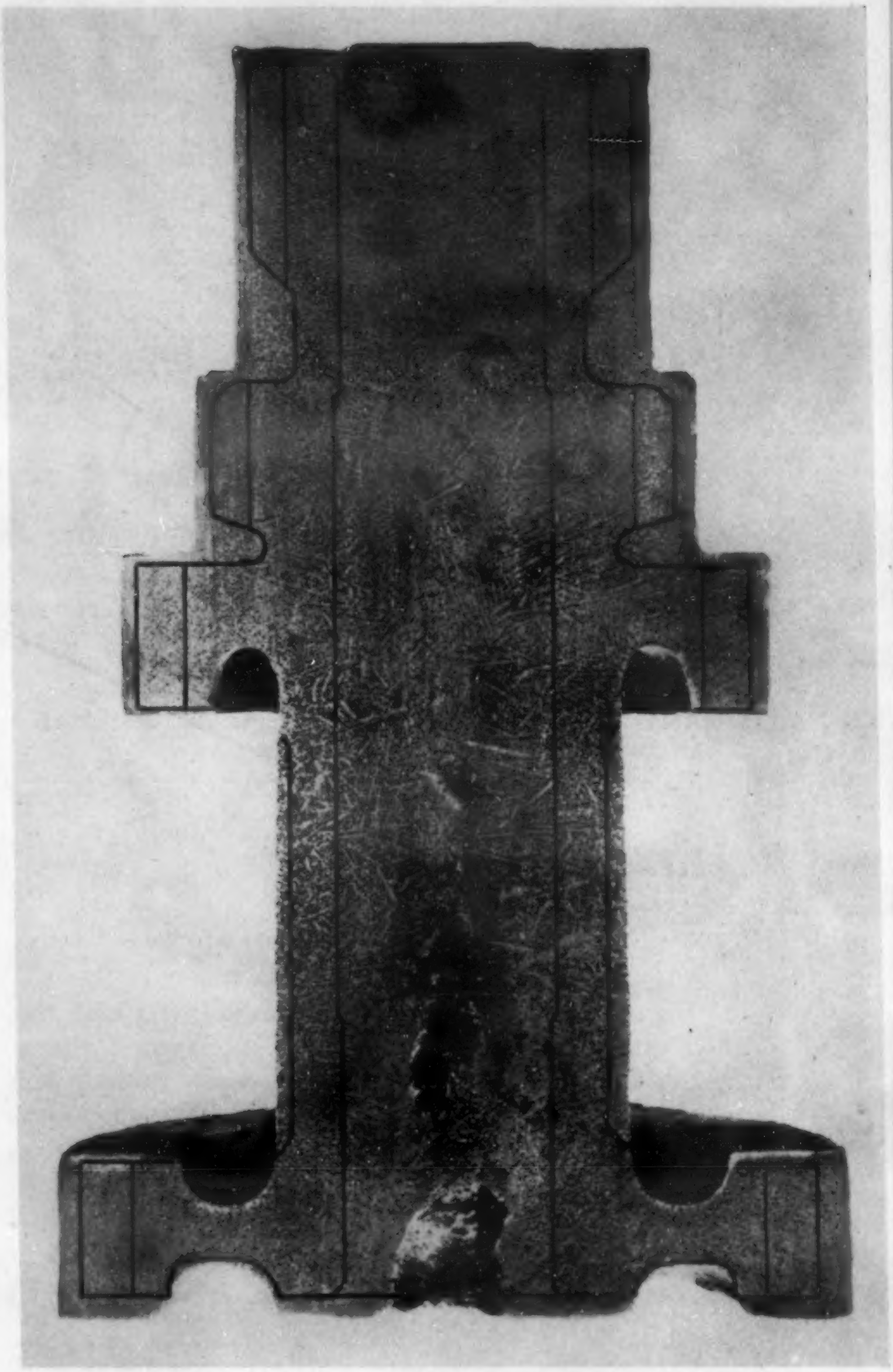


Microstructure of the Centrifugally Cast Steel Cluster Gear Blank in the normalized Condition. X 100.





Macrostructure of the Cluster Gear Blank As-Forged, Showing Flow Lines. The super-imposed dark lines show the outline of the finished cluster gear.



Macrostructure of the Cluster Gear Blank As-Centrifugally Cast, Showing Absence of Flow Lines. The super-imposed dark lines show the dimensions of the finished cluster gear.

demonstration of the DeLavaud process by the inventor himself, and of writing the first published description[3] of his method in this country. Since then, a great majority of the cast iron pipe produced in the United States is now made by the DeLavaud process as used by the U. S. Cast Iron Pipe & Foundry Co. (and others) and by the sand spun process, developed by the American Cast Iron Pipe Co.

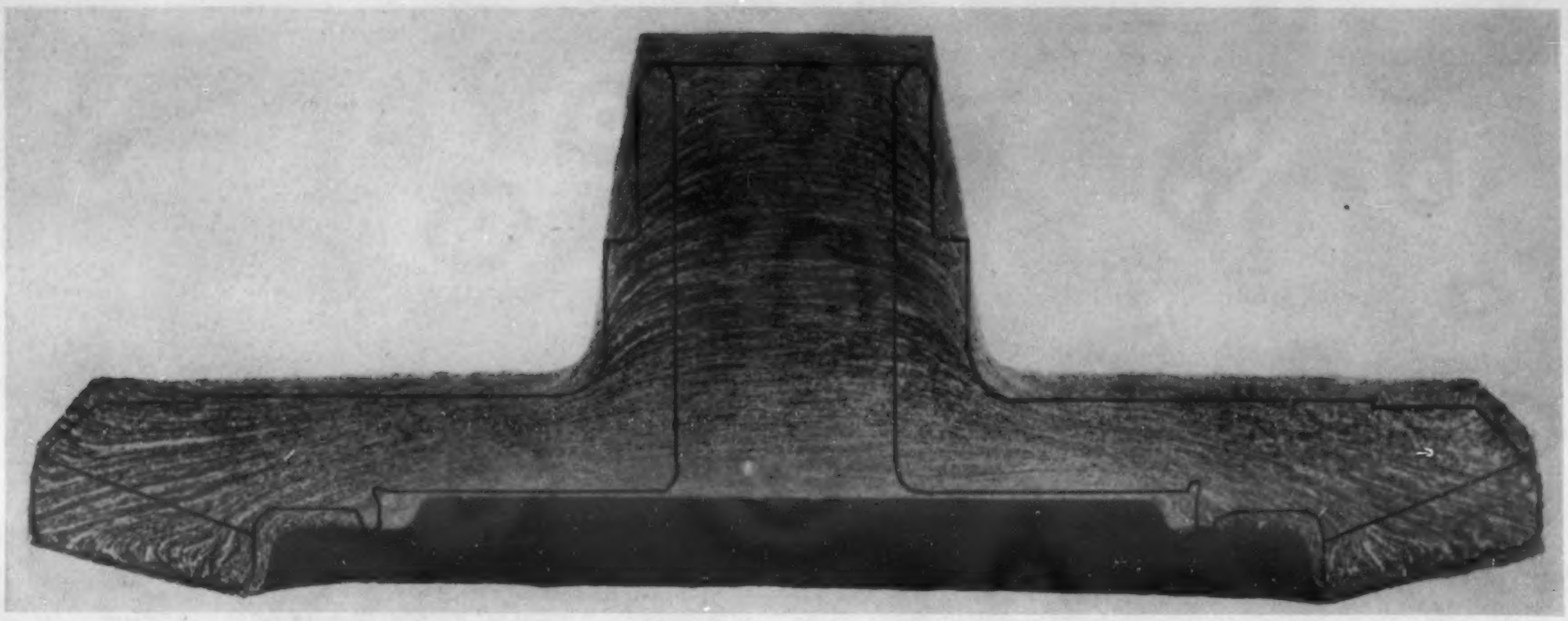
The Metal Saving Possible

The Ford metallurgical engineers have demonstrated that the cluster transmission gear blanks and the rear axle differential gear blanks, both passenger and truck, can be cast centrifugally with a marked saving in metal consumed and, somewhat to their surprise, with an enhancement in quality for the purpose. The table gives the relative amounts of metal involved in the two processes as determined by experience to date (September, 1938). The data speak for themselves. A further advantage will be discussed later—the structure of the metal—as well as other demonstrated ones.

Composition of the Gears

As stated earlier, previous to the development of the centrifugal process, forgings were used entirely as material for these gears. The forging steel used was approximately S.A.E. 5140. The steel incorporated in the centrifugal castings is quite similar except that at present copper is a constituent. The following table gives the composition range of the centrifugal castings with that of the forgings included for comparison:

	Castings	Forgings
Carbon	0.35 to 0.40	0.35 to 0.38
Manganese	0.65 to 0.80	0.65 to 0.80
Silicon	0.30 max.	0.10 to 0.20
Chromium	0.90 to 1.10	0.90 to 1.10
Copper	0.50 to 1.50	none
Sulphur	0.04 max.	0.04 max.
Phosphorus	0.03 max.	0.03 max.



Macrostructure of One of the Rear Axle Gear Blanks As-Forged. The super-imposed dark lines show the dimensions of the finished rear axle gear.

Table of Relative Weights of the Forged and Cast Gears

	Forging				Casting			
	Rough		Finished		Rough		Finished	
	lbs.	oz.	lbs.	oz.	lbs.	oz.	lbs.	oz.
Transmission gear.....	11	8	5	6	9	8	4	14
Rear axle passenger gear	20	5	10	12	17	8	10	12
Rear axle truck gear..	36	8	22	14	32	..	19	8

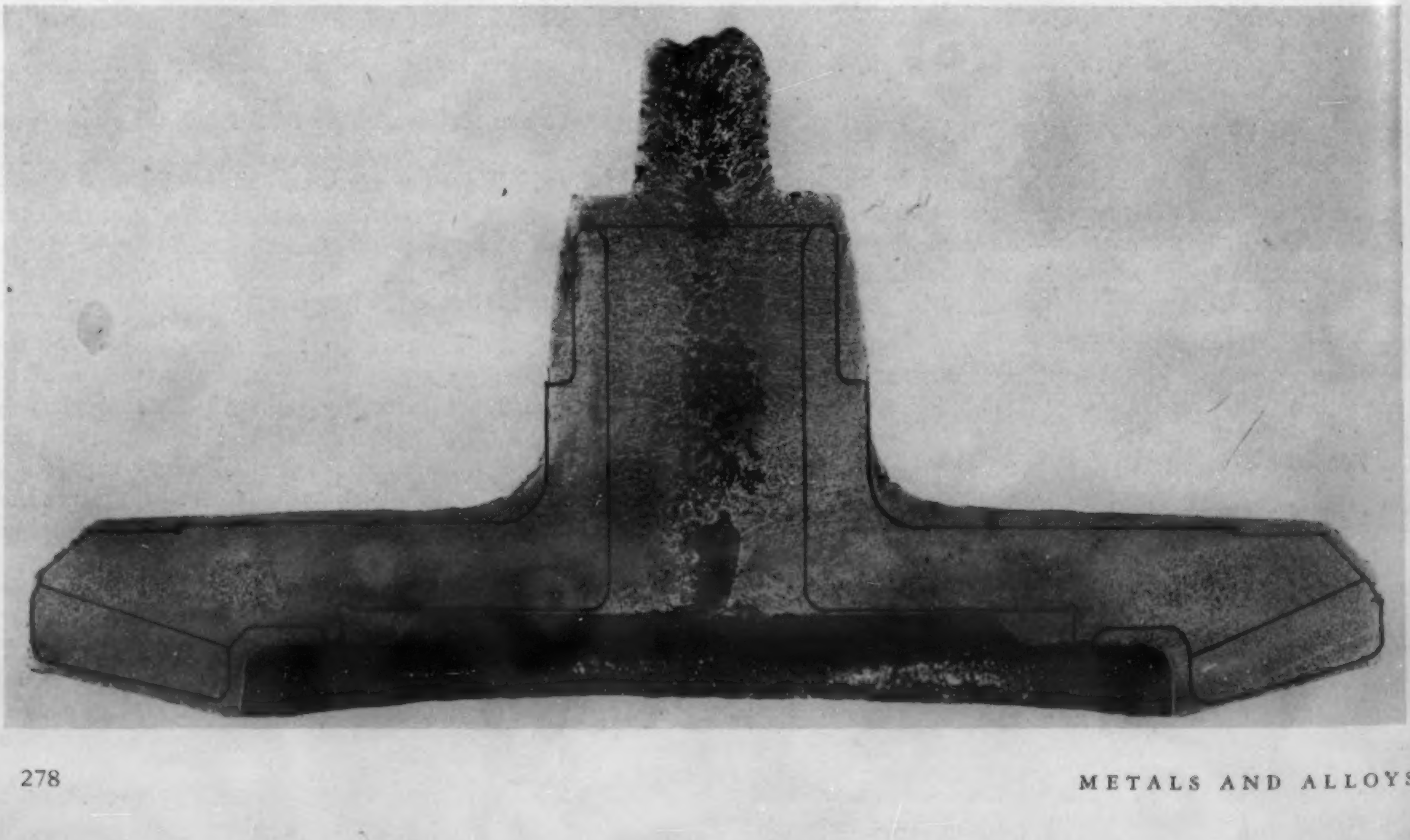
Note: 16 lbs. of molten steel necessary in the ingot for each forging blank for transmission gear.

The steel which is being cast centrifugally is a relatively high carbon copper-chromium steel. The range in copper is a flexible one, the proportions being varied as study and experience dictate. The steel is melted in a 4-ton electric furnace ('Lectromelt), 2 tons at a time being the quantity now being poured. From the furnace the molten metal is transferred directly to the spinning molds and in about 3 min. the rough gear blank is removed—a very rapid production process.

The Centrifugal Machines

At present eight centrifugal machines are in operation. The molds are now made of low carbon chromium-molybdenum steel. The best composition has not yet been settled on, some special analyses being experimented with. But an important factor here is that these molds are cheaper than forging dies. It is possible that later an analysis will be discovered that will prove to be more satisfactory as to life and efficiency.

The molds are set on a vertical axis so that the rotation



Macrostructure of One of the Rear Axle Gear Blanks As-Centrifugally Cast. Flow lines absent. The super-imposed dark lines reveal the outline of the finished rear axle gear. The protrusion at the top is the excess metal of the casting.

is in a horizontal plane. The revolutions, motivated by a motor underneath the molds, average 300 to 400 r.p.m. In the experiments, revolutions from 200 to 1,800 r.p.m. were used. The metal enters the mold at an average temperature of 2900 deg. F. By this process the metal can be put where it is most desired and hence the saving in weight is possible.

A problem which had to be solved and one which is not usually met with in centrifugal casting was a provision for the undercut portion of the cluster gears. Usually most centrifugal products are uniformly cylindrical. In this case Ford engineers solved the undercut difficulty by developing a sand core which is placed in the mold. This provides the undercut portion of the gear blanks. A novel provision is also the fact that two gear blanks are cast in one mold, with a small protrusion at each end for excess metal necessary.

The Heat Treatment Cycle

The heat treatment cycle of the centrifugally cast gears differs but little from that applied to the corresponding forgings. They are normalized after heating to 1700 to 1750 deg. F. by soaking and rather rapid cooling. The main difference is that the cooling rate is somewhat faster than for forgings. This is inaugurated so as to insure a Brinell number that is not too soft. The machinable hardness aimed at is about 190 Brinell. Following this treatment the gear blanks are machined, and the teeth cut.

The Macro and Micro Structure

The microstructure of the as-cast gears differs but little from that of the forgings. An extremely fine grain structure is obtained, ranging from 5 to 7 A.S.T.M. numbers.

A superior quality of the metal made by this process is revealed by the macrostructure brought out after etching. And this is pointed to as important. Macrostructures of the castings show that the crystal formation of the metal runs perpendicular to the forces to which the gear teeth will be subjected in actual use. In a forging, however, the flow lines developed as a result of the forging process are parallel to the lines of force. It is therefore evident that the centrifugally cast alloy steel gear is stronger than the forged. This has been demonstrated by many experiments and in service tests. The relative macrostructures are shown by accompanying macrographs.

The simplicity of the process is emphasized when it is pointed out that, in the production of forgings, the molten steel must first be poured into ingots which are then reheated in soaking pits, followed by rolling down to a forging billet which is then forged and machined to final dimensions. During this process about 25 per cent of the metal must be cropped and then remelted. These various steps involve three reheatings. The centrifugal process represents a relative metal saving of about 25 per cent.

Quality of the Steel

Besides the claimed advantages already pointed out, the centrifugal process assures a sound casting, free from blow holes and with practically no segregation. It also makes it possible to make a product at once which is closer to the desired final dimensions, cutting down the amount of machining. Equally important is the relative low cost of the process. And still more vital, as mentioned earlier, there is no sacrifice in quality. Shortcomings in quality or life are not tolerated. Three tests have been applied—conventional static tooth loading, impact properties, and accelerated life tests of complete transmissions. Indeed another star has been added to the diadem of the metallurgical accomplishments of the Ford engineers.

For those who are not familiar with some of the earlier developments of the Ford organization, which METALS AND ALLOYS has been so fortunate to have discussed, we may mention (besides the crankshaft and the piston articles) those relating the metallurgical facts about the camshaft,[4] the continuous pouring of cylinder blocks,[5] the valve seats,[6] and the brake drums.[7]

Group of Forged and Centrifugally Cast Steel Cluster Gear Blanks and Finished Gears as Well as the Cores Used. Upper right is the forged cluster gear blank and machined gear. Lower left is the centrifugally cast steel cluster gear blank (2 in one mold) and the finished machined cluster gear. Some of the cores used in the centrifugal mold are also pictured.

References

[1] "The Story of the Ford Cast Crankshaft." METALS AND ALLOYS, Vol. 6, Oct., 1935, pages 259-263.

[2] "The Lincoln-Zephyr Cast Alloy Piston." METALS AND ALLOYS, Vol. 7, Apr., 1936, pages 85-87.

[3] "Centrifugal Machine for Casting Pipe," *The Iron Age*, Sept. 7, 1916, page 506.

[4] "Manufacture of Ford Camshafts—How Metallurgical Control Is Achieved." METALS AND ALLOYS, Vol. 7, Nov., 1936, pages 275-277.

[5] "Continuous Pouring of Ford Cylinder Blocks." METALS AND ALLOYS, Vol. 6, Nov., 1935, pages 299-302.

[6] "The Manufacture of Valve Seat Inserts for Ford Engines." METALS AND ALLOYS, Vol. 8, Apr., 1937, pages 89-91.

[7] "The Metallurgical Story of Ford Brake Drums." METALS AND ALLOYS, Vol. 8, Nov., 1937, pages 303-306.

Under-water Drilling by the Submersible Barge Method as perfected by The Texas Co. This advancement has led to the development of oil-fields in the bayous and on the Gulf Coast of Louisiana and Texas, frequently hundreds of yards off shore. It is but an instance of the research The Texas Co. has pioneered in the petroleum industry to open up entirely new fields of development. (Courtesy: The Texas Co.)

METALS AND LUBRICANTS FOR

BEARINGS AND GEARS

AN EXTENDED ABSTRACT

Part II

(Concluded from September Issue)

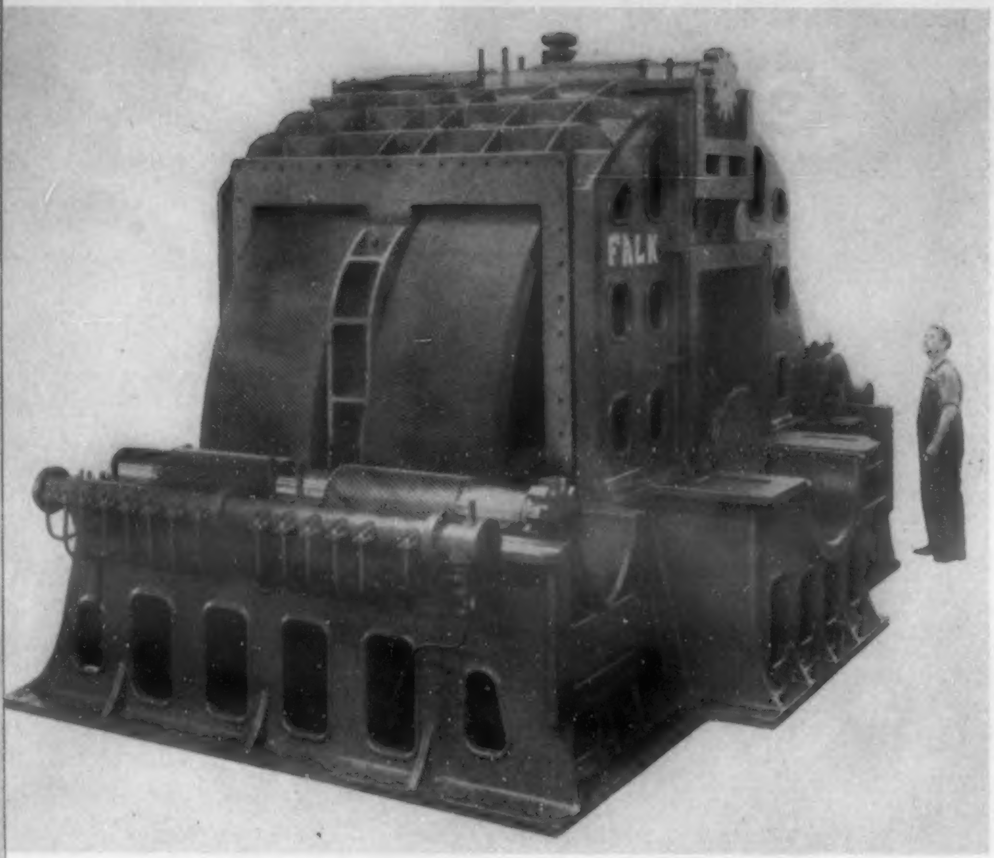
by R. W. Dayton

Battelle Memorial Institute, Columbus, Ohio.

PISTON RINGS AND CYLINDERS

THE lubrication of piston rings can be either of the fluid or boundary type. Bouman[45] says that at the extremities of piston travel, where the ring is moving at low speeds, boundary lubrication will exist, whereas midway in the ring travel, when it is moving rapidly, there will be fluid film lubrication. According to Higinbotham,[54] the coefficient of friction may, therefore, be as high as 0.10, thus causing a high friction loss. Bass[43] estimated that 70 per cent of the friction loss of an aero-engine took place in the pistons and rings and that 30 per cent of the waste heat was carried away by them. Furthermore, 80 per cent of this piston friction is caused by the rings, which operate under a very limited oil supply. A further appreciation of the severity of service of piston rings and cylinder walls can be had from Higinbotham's[54] data on the temperatures of operation. Measurements on the cylinder wall of a

Appearance of Diesel Engine Piston Ring Bearing Surface after Four Years' Service. Photomicrograph (left) shows appearance of the ring O.D. as removed from the engine and cleaned. Note the uniform size of the abrasive markings, pointing to good lubricating conditions and freedom from scoring or galling. Some slight etching of the surface is apparent, due to slightly corrosive nature of the fuel. This ring surface, as viewed with the naked eye appeared smooth and well polished. X 25. Photomicrograph (right) is same as other one, only after cleaning with alcohol and buffed slightly, 100 X. This view illustrates the size and form of the graphite flakes. Rings and cylinders, when properly lubricated, exhibit the desirable surface markings as shown. (Courtesy: Koppers Co., American Hammered Piston Ring Division)



This is a Partly Open View of One of the Units Used in the U. S. Liners "Manhattan" and "Washington." These are typical of single reduction units of the high ratio type used with rather slow speed turbines. In this case there are three turbines, triple expansion, all of which run at 1500 r.p.m. and mesh with a single gear and transmit a total of 15,000 h.p. at 125 r.p.m. The lubricant is a high grade turbine oil about 500 Saybolt seconds at 100 deg. F. and is distributed by pressure sprays to the gears and pressure feed to the bearings, which are all of the ordinary sleeve type (Courtesy: The Falk Corp., Milwaukee)

Diesel engine showed temperatures up to 424 deg. F., in a gasoline engine up to 530 deg. F., in a steam engine up to 300 deg. F., with saturated steam, and higher with superheated steam. Lubrication failure can be expected at over 400 deg. F., and then piston scuffing can cause temperatures up to 1,000 deg. F.

Ring sticking, scuffing, and wear are factors limiting the service life of these parts. Ring sticking is the result of chemical changes in the oil, and according to Bass,[43] Bouman,[45] and Rosen[66] may be either of two types, an oxygenated lacquer, rapidly deposited at low temperatures in the ring grooves, or a deposit of sludge and adventitious matter, which deposits at high temperatures over a long period of time. The first is caused by too rich a fuel mixture and is rather infrequent. The second is the more frequent cause.

Scuffing and seizure are due to a lubrication failure. Ottaway[63] says that, although cast iron pistons would seem to be able to run at lower clearances without seizure, they actually have a greater tendency to seizure, and the resulting seizures are much more disastrous. A tool finish for Diesel engine cylinder liners is preferred by Yeates,[72] since it is less prone to seizure. Compounded oils (Rosen[66]) and colloidal graphite in the oil (Higinbotham[54]) are said to reduce scuffing tendencies.

Wear

Wear is a problem of design, lubrication, and materials. Only a small amount of wear can be permitted in an internal combustion engine before blow-by and oil consumption become excessive. In steam engines, however, Stanier[67] says that large amounts of wear can occur without harmful effects.

According to Bass[43], the wear on the rings is the most serious part; wear on the cylinder walls is of little account. The design of automotive rings is particularly important in preventing wear, and in this respect Taub[68] thinks that United States practice is far superior to European, giving longer life, lower oil consumption, and higher efficiency. He discusses present United States practice, which is to use individually cast rings with uniform radial pressure. The pressure pattern is cast in rather than machined in. The tension is higher than in the past, but this is not important in wear, because tension accounts for only a small part of the force on the piston rings. At present, rings are made with a tapered facing, which permits oil control until the ring is well seated. Chemical treatment (though what it is was not mentioned) was said by Rosen[66] to enable wearing-in to occur much more rapidly.

Yeates[72] gives data which show conclusively that a large amount of stopping and starting give a much increased wear per 1,000 hrs. running time. Williams[71] determined the effect of oil viscosity on cylinder wear, finding that with continuous running, light and heavy oils were equally good. With frequent stopping, light oils gave greater wear.

Wear, according to Bouman[45] and Young[73] can be due either to insufficient lubrication, abrasion, or corrosion. The type of cylinder liner should be selected to best resist the type of wear which will be predominant in service. For cases where abrasive wear will be dangerous, sheer hardness must be relied upon. Nitrided liners are finding use in such applications (Pearce[64]), though it is said by Young[73] that the best type of liner will vary with the type of dust.

Ottaway[63] and Pearce[64] feel that cylinder irons of the austenitic type, such as Ni-Resist and Nicrosilal, successfully resist corrosive wear.

For other uses, gray irons are most often used. There is general agreement that a fully pearlitic iron should be used and that a little free cementite should be present to avoid any traces of ferrite. There is less general agreement about the presence of the phosphide eutectic. Pearce[64] claims that it improves, Chatel[47] that it harms the wear resistance of iron. Young[73] says that ferritic irons are somewhat improved by phosphorus but that ferritic irons are bad at best. The function of alloying elements was only considered insofar as they affected structure.

King,[86] using iron for the inner tubes of textile spindles, finds that a plain cast iron is better than bronze, lignum vitae, alloy irons, and fabric resins from the standpoint of economy and cost. Tests, reproducing actual conditions, showed that phosphorus somewhat improves wear resistance, though not so greatly as combined carbon. He found the best solution of his problem was to use an iron of about 0.50 per cent combined carbon with a phosphide network, and then good wear resistance plus machinability was obtained.

The desirable surface to be put on liners depended upon their hardness; a tool finish was preferred for soft irons, whereas lapping is essential for very hard irons. Yeates[72] feels that a tool finish is less sensitive to the grade of oil used than a more finely finished one. A sensitive method of determining wear was developed by Everett and Keller,[50] who analyze the crankcase oil for iron contamination.

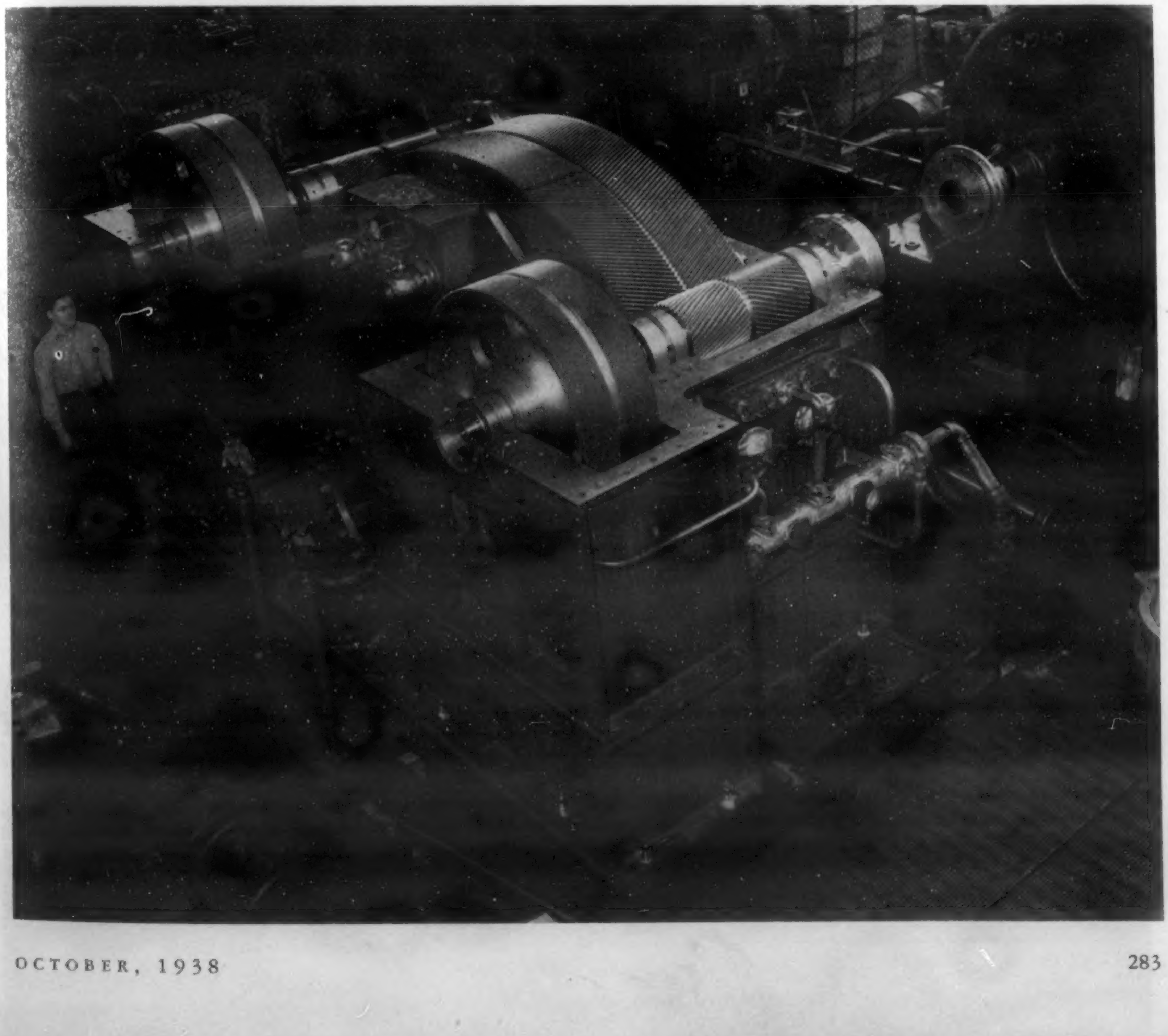
GEARS

GEARS, WORKING under very extremely high unit loads, are subject to many types of failure, which are discussed by Merritt.[88] In addition to direct breakage of teeth, usually caused by abuse, such an overloading or insufficient lubrication, there are many types of surface failure. Types of gears, in which there is chiefly rolling friction, such as spur, helical, or bevel gears, may be subject to smooth abrasion, in which the teeth wear at a fairly rapid rate yet maintain a polished surface. The failure is thought to be due to occasional breakdown of the oil film, each breakdown resulting in a little wear. A more viscous lubricant often cures this situation. Local seizure, caused by local breakdown of the lubricating film, gives the type of failure known as scuffing. This has lately become very serious with gears under very high unit loads, in which there is considerable sliding friction, such as spiral bevel and hypoid gears. E. P. lubricants are established as combatants of this type of failure. Merrit mentions the case of certain gears which require running-in with E. P. lubricants but thereafter run satisfactorily with ordinary gear oils. This emphasizes the fact that the wearing-in period for gears is the time when scuffing is most apt to occur.

Blok[75] made measurements of the temperature flash on the surface of planetary gear teeth during meshing, working under E. P. lubricating conditions, and found that with unit loads of about 140,000 lbs. per sq. in. the average

Open View of a Modern Double Reduction Drive for a Tanker. In this case we had to meet the condition that the high speed gears run at unusually high velocity and this applies to the journal speeds of the high speed pinion bearings. Journal speeds and tooth velocities are relatively much lower for all the rest of the unit. Again we use a high grade turbine oil which is fed under gravity pressure through sprays to the teeth and directly to the bearings. A suitable oil can be any viscosity between 350 and 600 Saybolt sec. at 100 deg. F. We prefer the higher figure because it gives better protection to the slow speed gears of the unit but we make special provision to provide a lighter grade of oil from the same original source for use exclusively in high speed gear teeth and high speed pinion journals by the following simple device:

Nearly all of the oil fed to the unit passes first through a suitable cooler, then to a gravity tank from which it is fed to all of the low speed elements at a temperature of 110 deg. F. However, we provide a by-pass between the oil pump and the cooler which delivers oil at about 125 deg F. and consequent lower viscosity to a supplementary small tank which is mounted directly on the unit. Oil from this tank is fed directly to the gears and pinion bearings, only, of the high speed trains and, in that manner, is conditioned more suitably for extra high speed gears and journals without sacrificing the protective value of the heavier cooled lubricant that reaches the rest of the unit. (Courtesy: The Falk Corp., Milwaukee)



temperature flash was about 60 deg. C. and calculated that the maximum temperature flash was two to three times that. These gears were working under well lubricated conditions, and it can be readily appreciated that a lubricant breakdown could cause very much higher surface temperatures. Such a condition leads to local seizing (welding), or scuffing.

Merritt also discussed ridging, or dragging, which is an extension of scuffing, in which the contour of the tooth is changed due to plastic flow caused by seizure. The pitch line of the driving gear is grooved; the driven gear is correspondingly ridged.

Pitting can occur on any gear or material and is caused by fatigue failure due to local high stressing. Small particles of metal are removed by fatigue cracking in a local area. This type of failure can develop early in the life of a gear, before it is completely worn in, and when local high spots cause excessively high stress.

E. P. Lubricants

E. P. lubricants received the greatest amount of attention in the papers on gears. Evans[81] and Miller[89] devoted their papers to general discussions of the lubricants. Essentially, E. P. lubricants are mineral oils to which certain active substances (Pb soap, S, Cl, Se, or compounds of them) have been added. The additions greatly improve resistance of films of the lubricant to rupturing and, thus, prevent scuffing. This property of the lubricant is called film strength, and the high film strength of these lubricants is generally associated with a chemical reaction between the lubricant and the metal, forming a non-metallic film which keeps the metal surfaces apart. Certain of these lubricants can be very corrosive; others are less so. The only suitable way to measure corrosion is thought to be in the particular assembly in which it is to be used. No laboratory tests have proved very useful.

Many types of machines are in use for testing the lubricating properties of these E. P. lubricants. Evans[81] thinks that the results of all are arbitrary and not conclusive; Miller[89] thinks the Timken machine the best. Four different types of testers are compared experimentally by van der Minne.[124] These are as follows: (1) The four-ball tester, in which a loaded steel ball is revolved on three others and is started under load; (2) Timken tester, in which a steel block is pressed against a revolving ring; (3) Floyd tester —a steel shaft revolves in two steel half bushings which are pressed together; (4) S.A.E. tester, in which two steel disks are pressed together while rotating at different speeds. van der Minne comes to the conclusion that all the testers are less exacting than the hypoid gear itself, and the hypoid gear is the best way of testing various lubricants.

Southcombe, Wells, and Waters[120] and Clayton[78, 107] investigated the operating characteristics of types of E. P. testers, with less emphasis on the correlation of results with service than seems desirable.

MISCELLANEOUS

Wire Drawing: Thompson[96] believes that at ordinary speeds, lubrication in wire drawing is of the boundary type and, as proof of this, shows that the pull required is

Closed View of a Modern Double Reduction Drive for a Tanker. (Courtesy: The Falk Corp., Milwaukee)

independent of speed of drawing within the range of 20 to 600 ft. per min. Goodacre[83] also believes this to be so and says that the die friction consumes about 50 per cent of the total energy required for drawing. He believes that an adsorbed film of lubricant exists on metals due to the unsaturated nature of their surface and attributes the difficulty of drawing stainless wire to the saturated nature of its surface.

Soft metal coatings on wire assist in its drawing. Copper or tin improves the wet drawing of steel and reduces die friction by about one-half. Lead improves the drawing of Nichrome, but it can give trouble in subsequent bright annealing. Thompson[96] says that lead coatings on stainless enable more work to be done between anneals, even though the pull required is greater. Below 70 per cent reduction, the properties of the wire are the same whether or not it is lead coated. Above 70 per cent the lead-coated wire seems softer and more ductile.

Cold Pressing of Sheet Steel: Arrowsmith[74] says that the function of the lubricant is primarily to maintain surface finish and to prevent tearing of the pressing. More severe requirements are now causing a demand for better lubricants. A lubricant breakdown, causing high friction, may

Sugar Mill Bearings of Ampco Metal Grade 16. Water cooling channels were cast into these bearings for cooling effect. (Courtesy: Ampco Metal, Inc., Milwaukee)

either tear the pressing or give cold welding (seizing).

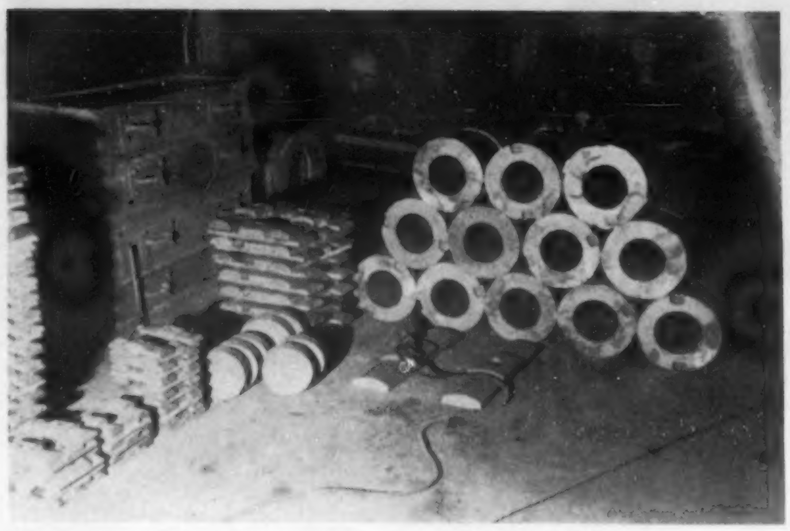
Cutting Fluids: Miller[90] lists the requirements of a cutting fluid as follows:

1. Cool tool and work.
2. Decreased friction of tool against work.
3. Flushing action.
4. It must wet the metal quickly.

Lloyd[87] shows that the lubricant desired will vary according to use; that is, for high-speed rough work, cooling is the most necessary function of the cutting fluid and, therefore, a fluid of high cooling capacity, such as a waterbase lubricant, is needed. On the other hand, when cooling is not so important, and where complicated and expensive tools are used, the preservation of the tool is very important; so straight oils, which decrease friction, are used.

Boston[76] feels that the cutting fluid has very little influence on the surface of the machined article.

All three state that the stability of a water-base emulsion is very important, since, if the emulsion breaks down, the machine will rust.



Screwdown Nuts, Universal Joint Bearing Segments and Thrust Washers for Installation in a New Continuous Sheet Mill. Aluminum bronze. (Courtesy: Ampco Metal, Inc., Milwaukee)

Chains and Wire Ropes: Both of these applications are places where abrasive material may have opportunity to come in contact with rubbing surfaces. Coulson,[80] for lubricating chains under such conditions, states that the lubrication must come from inside the bearing pin out to prevent abrasive from exerting a lapping action, and he also says that if this is impractical no lubricant may result in a longer life than if lubricant were applied to the outside. For the same reason, Hogan[85] says that the only lubricant which should be applied to wire ropes in cases where abrasive may be present is that used in the manufacture of the rope. In certain mines, where corrosion may be the chief cause of low life, lubrication is desirable to prevent it. In both chains and wire ropes, except for cases where abrasive wear may be severe, lubrication is desirable to reduce friction or to increase life.

References:

[The entire list of references was published with Part I in the September issue.]

Centrifugally Cast Controllable Pitch Propeller Bushings. Ampco Metal Grade 18 for the Hamilton Standard Propellers, Division of United Aircraft Corp., shown as cast, as shipped, and as finished. (Courtesy: Ampco Metal, Inc., Milwaukee)

THE PRODUCTION AND

Industrial Uses of Titanium

—A CORRELATED ABSTRACT

Part I

by George F. Comstock

Metallurgist, Titanium Alloy Mfg. Co., Niagara Falls, N. Y.

Not every one, of course, shares the complete misapprehension concerning the usefulness of titanium mentioned by Mr. Comstock in his first paragraph. But, many of us, aware though we be that titanium is plentiful and much more than a metallurgical superstition, will be surprised at the number and breadth of industrial applications of this metal revealed by the author.

Modern industry can credit much of "that extra something" of its products to the use of the hitherto "unfamiliar" metals in the materials from which its products are fashioned. Just how much "umph" titanium can confer on steel, cast iron and various non-ferrous alloys is clearly described in this article.

This article is based on an address delivered by the author before a local chapter of a technical society.—The Editors.

TITANIUM WAS ONCE REGARDED as a rare element of little use, and even today many think of it as a sort of dope forced by fair means or foul on gullible steel makers who pay out their good money for it, to the benefit of no one but the alloy salesman. Both of these ideas are of course incorrect, as this article will show, for titanium is not only one of the most plentiful of metallic elements, but also a very important and widely used industrial material, whose availability and application have benefited the alloy salesman least of all.

General Uses

The chief use of titanium today is for pigment in the

Fig. 1. Microstructure of High-Carbon Ferro-Carbon-Titanium Unetched and Magnified 100 Diameters, Showing Dark Graphite Flakes and Gray Titanium Carbide Particles.

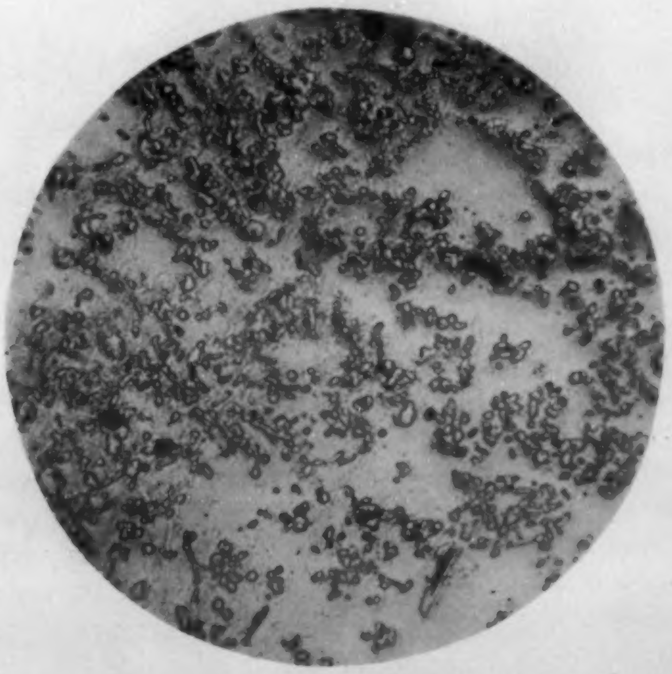


Fig. 2. Microstructure of Medium-Carbon Ferro-Carbon-Titanium, Unetched and Magnified 100 Diameters, Showing Fine Titanium Carbide Particles and No Graphite.

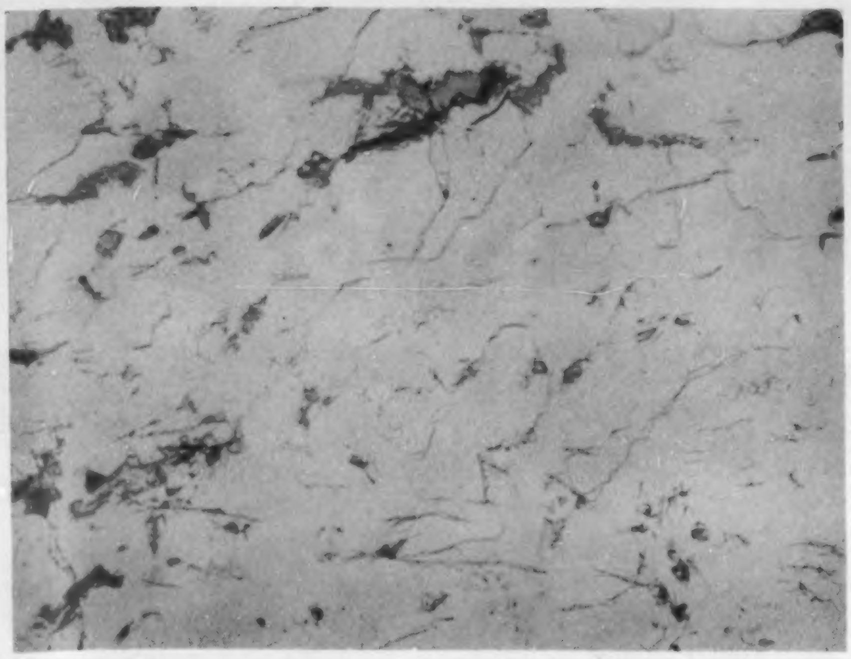


Fig. 3. Microstructure of Low-Carbon Ferrotitanium, Etched with HF and HNO_3, and Magnified 200 Diameters, Showing No Graphite or Carbide.

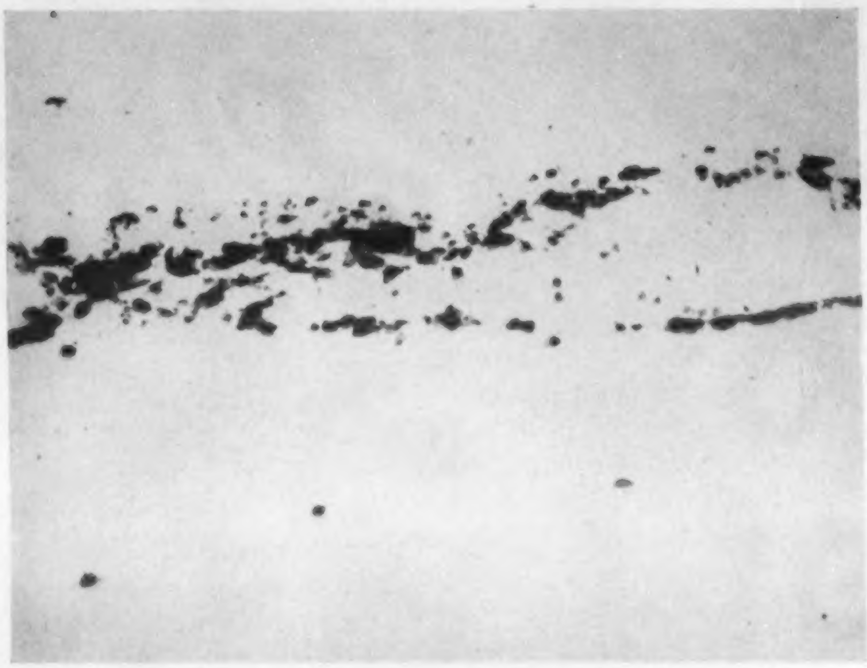


Fig. 4. Typical Segregated Alumina Inclusions in Soft Steel Treated with Aluminum, Unetched and Magnified 200 Diameters. These inclusions caused a defect in a bent sheet.

paint industry,[1] and this accounts for nearly 90 per cent of the total production. The pure oxide of titanium, properly precipitated from sulphate solution, is a white powder of very high refractive index, which means that it takes only a comparatively thin layer to interfere with the transmission of light and prevent the appearance of any markings underneath. Thus even though this pigment may cost more than others, its use is economical because fewer coats of paint are needed to secure a perfect finish. Much of this oxide pigment finds its way into such products as linoleum, rubber, artificial leather, plastics, cosmetics and paper, where valuable results are obtained as well as in paint.

The next largest use of titanium is probably in metallurgy, but this is by no means confined to the deoxidation of steel. This element is used not only as ferrotitanium to deoxidize iron and steel, but also as a true alloying element in aluminum, copper and nickel as well as in steel and iron. Another metallurgical use which is growing rapidly is in welding rod coatings,[2] where the fluxing and electrical properties of titanium dioxide in the form of powdered rutile have been found of great value. Before describing these metallurgical uses more specifically, it would perhaps be worth while to explain why titanium is not really a rare element.

Natural Availability

Among the elements composing the earth's crust titanium is the tenth in order of abundance, being much more plentiful than many of the well-known metals such as copper, nickel, lead and zinc. This is shown by Table I (taken from Kemp's "Handbook of Rocks," 1906) where it can be seen that iron, aluminum, and magnesium are the only engineering metals that have been supplied more abundantly for man's use than titanium. Furthermore, concentrated deposits of high-grade titanium ore are not particularly scarce as ore deposits go. In this country large deposits of titaniferous iron ore are found in the northern part of New York as well as in Virginia and Wyoming. The ores we use chiefly at Niagara Falls come from Canada, India, Australia, and Brazil. Three or four years ago the world production of ilmenite, only one of the ores of titanium, was reported as around 70,000 tons.[3] The total imports of ilmenite into this country amounted to about the same tonnage.

Titanium is not an especially costly metal, even in the unalloyed state. Table II for instance, shows that the present price of $6.50 per pound with a purity of about 99 per cent compares favorably with the prices of such metals as tungsten, molybdenum, tantalum, vanadium, and columbium. The price of the metal in alloy form is of course

Table I.—Composition of the Earth's Crust.

	Per Cent
Oxygen	49.98
Silicon	25.30
Aluminum	7.26
Iron	5.08
Calcium	3.51
Magnesium	2.50
Sodium	2.28
Potassium	2.23
Hydrogen	0.94
Titanium	0.30
Carbon	0.21
Chlorine and Bromine	0.15
Phosphorus	0.09
Manganese	0.07
All others	0.10
Total	100.00

Table II.—Approximate Prices of Commercially Pure Metals, per lb.

Platinum	$525.00
Gold	509.00
Palladium	410.00
Tantalum	88.00
Beryllium (as Cu-Be)	30.00
Silver	6.50
Titanium (98%)	6.50
Vanadium (92%)	6.00
Zirconium (95%)	5.00
Molybdenum	2.75
Tungsten	2.60
Cobalt	1.75
Calcium	1.50
Vanadium (as Fe-V)	2.90
Columbium (as Fe-Cb)	2.50
Titanium (as Low-C Fe-Ti)	1.20

much lower, down to as little as 40c per pound in medium-carbon ferrotitanium.

Smelting of Titaniferous Ores

The element titanium was discovered in the early days of chemistry, in 1789, previous to the discovery of such well-known elements as aluminum, calcium, chromium, magnesium, vanadium, etc. Its practical utilization however is very much more recent. At first it was known to iron-smelters chiefly as a nuisance, owing to its interference with

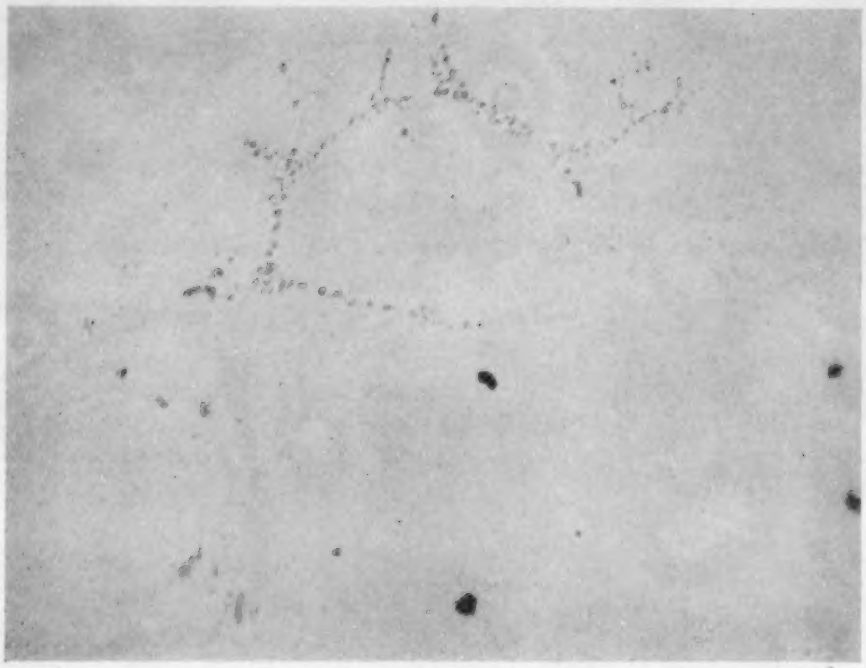


Fig. 5. Sulphide Inclusions in Network Arrangement in an Aluminum-Treated Cast Steel, Unetched and Magnified 200 Diameters. Such inclusions cause low ductility in tension.

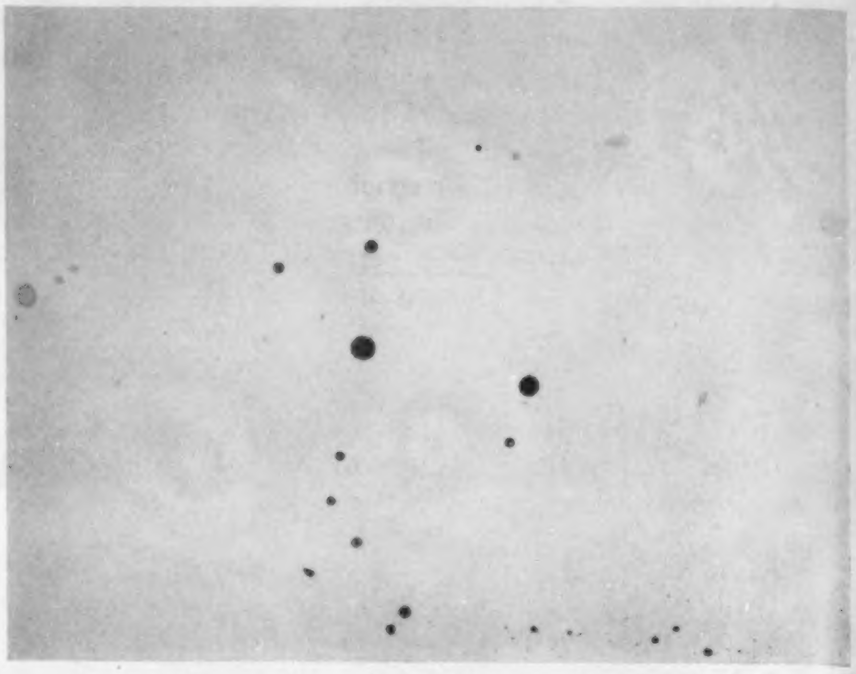


Fig. 6. Typical Scattered Globular Inclusions in a Titanium-Treated Cast Steel of Good Ductility, Unetched and Magnified 200 Diameters. The darker inclusions are silicates, and the lighter, sulphides.

slag compositions and the formation of infusible titanium cyanonitride in the blast-furnace hearth. Dr. A. J. Rossi, who died in Niagara Falls about 15 yrs. ago, was chiefly responsible for showing how titanium could be employed usefully.[4] He was hired in 1892 by the owners of the large deposit of titaniferous iron ore in the Adirondack mountains of northern New York to show how this ore could be smelted in spite of the prejudice that had arisen against the presence of titanium in a blast-furnace charge. Although Rossi was technically successful in this work, the ore, which by the way is very rich in iron and low in phosphorus and sulphur, has not yet been used commercially, largely on account of its long distance from a railroad.

Dr. Rossi's first experiments on smelting titaniferous iron ores were carried out in Buffalo in a good-sized experimental blast furnace. He made in it some excellent cast iron which contained titanium, and this led to the idea of making a high titanium alloy to be added to other cast iron to improve its quality likewise. From this it was but a short step to the addition of the same titanium alloy to steel, and when the manufacture of the alloy was started in 1900 at Niagara Falls its value as a deoxidizer for steel was soon established.

At the same time other metallurgical engineers in Germany and France were also working with titanium to investigate the possibilities of using this unfamiliar element. In Germany Dr. Hans Goldschmidt promoted a low-carbon ferrotitanium in competition with Dr. Rossi's alloy which had a fairly high carbon content. There was quite a controversy[5] for many years around 1910 as to which alloy was the best; this was never really settled inasmuch as both kinds are used today and have their own special fields of usefulness.

One of the most-used methods for smelting titanium ores

Fig. 7. Typical Graphite Flakes in Electro-Melted Cast Iron Unetched and Magnified 50 Diameters.

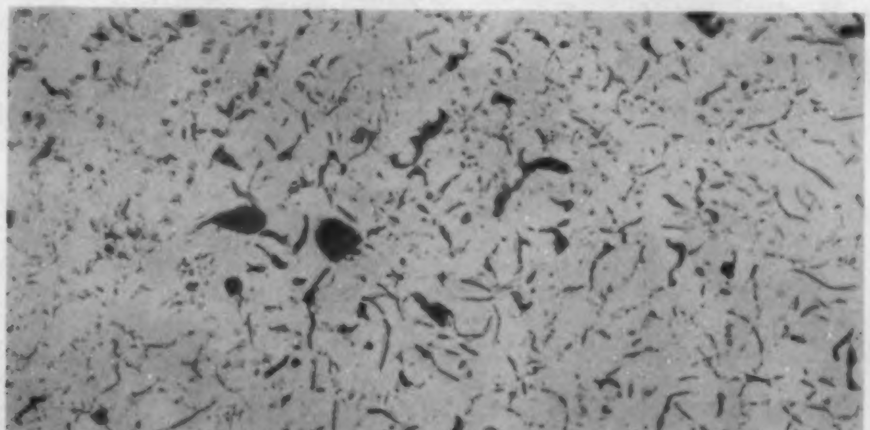
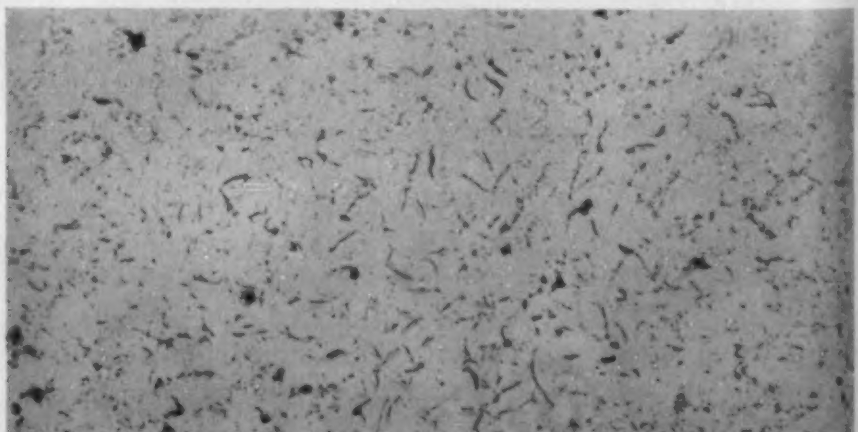


Fig. 8. Finer Graphite Flakes Typical of Titanium Cast Iron, Unetched and Magnified 50 Diameters. The methods of manufacture and composition (except for the titanium addition) applying to Figs. 7 and 8 were the same.



to make the alloys used for treating steel, cast iron, etc., is Rossi's process of carbon reduction,[6] which gives ferro-carbon-titanium containing 16 to 21 per cent titanium and 3 to 8 per cent carbon. The other common process is Goldschmidt's method by reaction with powdered aluminum,[7] giving low-carbon ferrotitanium containing 22-42 per cent titanium and 3 to 8 per cent aluminum. Typical microstructures of the products of these processes are shown in Figs. 1, 2, and 3.

Deoxidizing Steel

Rossi's process requires an electric furnace to provide the necessary high temperature, while in the other process the burning of the aluminum powder affords sufficient heat. The use of carbon as a reducing agent for the titanium ore is of course cheaper, and gives the least expensive titanium alloy. This is the alloy used so much as a deoxidizer for steel,[8] this use of titanium being commercially its most important metallurgical application. This is probably so well known to most readers as to require but little discussion here.

Titanium is a stronger deoxidizer than manganese or silicon, but not so strong as aluminum.[9] Its advantage over aluminum is that when used in the small quantities required for deoxidation its oxide does not remain in the steel to make it dirty as alumina does. Streaks of inclusions like those shown in Fig. 4, for instance, are not found in steel properly treated with titanium instead of aluminum.

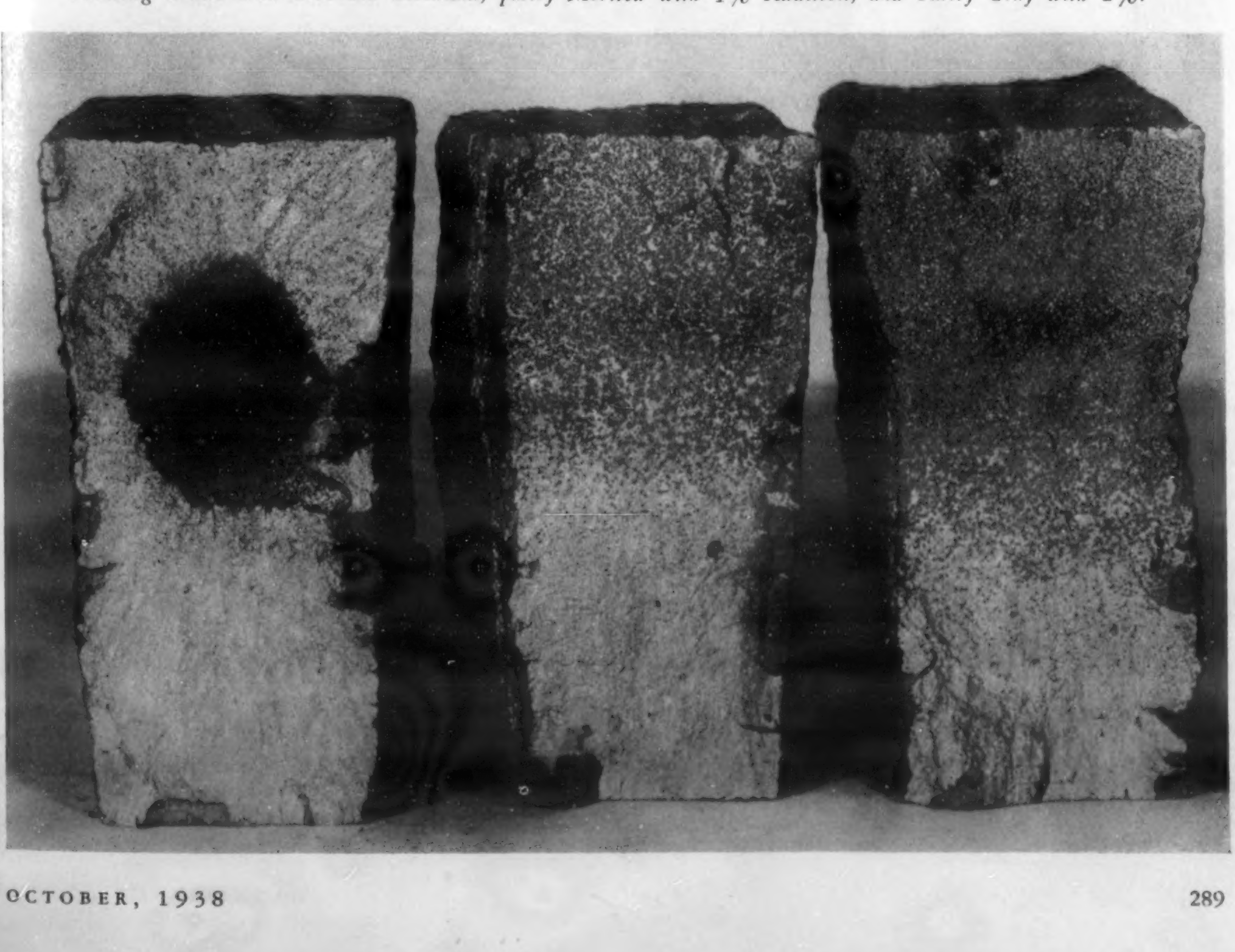
The oxide of titanium is an active flux for slag,[10] and is even capable of substitution for fluor-spar in open-hearth practice. Thus, the slag inclusions in titanium-treated steel are more fusible and fluid because of the presence of titanium oxide, and are therefore more readily eliminated by floating out of the freezing steel, giving cleaner metal.

Probably the largest amount of titanium is now used in effervescing steel, for many plants have found it to give better rimming ingots and hence a higher yield of good product.[11] The reason for its use in rimming steel is not entirely because of the deoxidation value, but partly because of the fluxing action of the titanium oxide formed. This affects the surface tension of the gas bubbles formed in the steel so that the effervescence is promoted and the gas is more readily eliminated before the metal becomes pasty, thus giving a cleaner, denser rim in the ingot.

Titanium also has an interesting field in cast steel, especially the pearlitic manganese steel,[12] where a stronger deoxidizer than silicon is needed. The use of aluminum for this purpose gives poor ductility because of the network sulphide arrangement typical of over-reduced cast steel,[13] as shown in Fig. 5. When titanium is used instead, the inclusions are globular and scattered like those in Fig. 6.

Titanium is used in steel castings, therefore, to give the proper degree of deoxidation for fine-grain characteristics such as good ductility, high impact value, and repression of grain-coarsening in heat treatment above the best temperature, without so much deoxidation as to incur trouble from inclusions.

Fig. 9. Fracture Tests of Cast Iron for Chilled Rolls, Treated with Various Amounts of Ferrotitanium as Indicated, Showing White Iron with No Titanium, partly Mottled with 1% Addition, and Partly Gray with 2%.



Titanium in Cast Iron

Low-carbon titanium alloys are required for adding titanium effectively to cupola-melted cast iron, to nickel, copper, aluminum, or as an alloying element in steel. One way of making a low-carbon alloy is by reduction with aluminum, and this can be done either in a bath of molten aluminum in a furnace,[6] or with powdered aluminum in a cold crucible.[7] In the latter method it is necessary to reduce some other oxide, such as iron oxide or nickel oxide with the titanium oxide, because the reduction of titanium oxide alone by aluminum does not generate enough heat to liquefy the products of the reaction so that the slag will separate from the alloy produced.

Therefore, pure titanium metal cannot be made in this way by aluminum reduction. Another way of making low-carbon titanium alloys is by reduction with silicon in an electric furnace, a method first proposed by Dr. Becket of the Electro Metallurgical Co.[14] Although titanium at steel-making temperatures reduces silicon readily from silica in slags, the reaction can be made to go the other way at the higher temperature of the electric smelting furnace under strongly reducing conditions in the presence of an excess of silicon. And even in a carbon furnace, the excess of silicon keeps the alloy from absorbing carbon above a very small amount. The titanium alloy used most in cast iron, where aluminum is objectionable, is made in that way. This alloy with a silicon content dissolves more quickly in cupola-melted cast iron than does high-carbon ferrotitanium, which, however, can be used with success in electric-melted cast iron.

Titanium is now quite widely utilized in cast iron,[15] chiefly to decrease the size of the graphite flakes, as it is more effective for that purpose than other alloy additions.[16] Figs. 7 and 8 illustrate this effect of titanium. As a consequence of the closer grain or finer structure of titanium cast iron, the strength is generally improved 5 to 25 per cent, with a slight increase in Brinell hardness, although the machinability is better.

Not only does titanium refine the grain of cast iron, but it also acts as a graphitizer, reducing the hardening effect of chill at thin sections and corners.[17] This is illustrated by the fractures shown in Fig. 9. Titanium is thus a useful addition to chromium cast iron[18] or vanadium cast iron,[19] where it permits the full utilization of the strengthening effects of those elements while counteracting their tendency to promote chilled and unmachinable thin sections and corners. The graphitizing influence of titanium accounts for the improvement it effects in the machinability of these harder cast irons, while its grain-refining influence maintains or augments their inherently high strength. It has also been found that the soundness of sand-cast test-bars of gray cast iron is improved when the iron is titanium-treated.[20]

(To be Concluded)

References

[1] A. W. Hixson & W. W. Plechner. "Titanium Offers New Possibilities as a Pigment". *Chem. & Met. Eng.*, Vol. 36, 1929, p. 76.
[2] L. B. Bliss. "Welding Rod Coatings". *Iron Age*, Vol. 134, July 26, 1934, p. 30.
[3] P. M. Tyler. "Titanium, Its Supply and Economics". METALS AND ALLOYS, Vol. 6, 1935, p. 132.
[4] A. J. Rossi. "The Smelting of Iron Ores". *Iron Age*, Feb. 6 and Feb. 20, 1896. Also *Trans. Am. Inst. Mining Engrs.*, Vol. 21, 1893, p. 832.
[5] Discussion on Titanium Alloys. *Met & Chem. Eng.*, Vol. 9, 1911, pp. 485-529. Also *Iron Age*, Nov. 16, 1911, p. 1056.
[6] A. J. Rossi. Acceptance of Perkin Medal. *J. Ind. & Eng. Chem.*, Vol. 10, 1918, p. 138.
[7] U. S. Patent 578,868, Mar. 1897.
[8] G. F. Comstock. "The Use of Titanium in Steel Making". *Blast Furnace & Steel Plant*, Vol. 21, 1933, p. 412.
[9] J. Chipman. "Application of Thermodynamics to the Deoxidation of Liquid Steel". *Trans. Am. Soc. Steel Treating*, Vol. 22, 1934, pp. 427, 431.
[10] Effect of Titanic Acid on Fusibility of Fire-Clays". Collected Writings of Herman A. Seger, Vol. 1, 1902, p. 519. Also "A Solution of the Titanium Problem". F. L. MacCallum. *Iron & Steel of Canada*, Vol. 4, Oct., 1921, p. 254. Also "Fusibility of Open-Hearth Slag Containing Titanium Dioxide". G. F. Comstock. *Chem & Met. Eng.*, Vol. 26, Jan., 1922, p. 165.
[11] "Canned Food Containers". *Nat'l. Canners Assoc. Bull.* 22 L, 1923. Also "Treatment of Steel with Ferro Carbon Titanium". G. F. Comstock. *J. Iron & Steel Inst.*, Vol. 114, 1926, p. 405. Also Report of Open-Hearth Committee Meeting. *Iron Age*, Vol. 122, 1928, p. 1297. Also "The Sticking of Thin Sheets". W. Titze. *Stahl u. Eisen*, Vol. 49, 1929, p. 897.
[12] G. F. Comstock. "Titanium Improves Pearlitic Manganese Steel". METALS AND ALLOYS, Vol. 8, May, 1937, p. 148.
[13] G. F. Comstock. "Aluminum and Titanium as Deoxidizers". *Iron Age*, Vol. 114, 1924, p. 1477. Also "Inclusions, Their Effect, Solubility and Control in Cast Steel". C. E. Sims & G. A. Lilliequist. *Trans. Am Inst. Mining & Met. Engrs.*, Vol. 100, 1932, p. 154.
[14] U. S. Patent 940,665, Nov., 1909.
[15] E. R. Starkweather. "Titanium in Cast Iron". *Trans Am. Foundrymen's Assoc.*, Vol. 45, 1937, p. 816.
[16] A. L. Norbury & E. Morgan. "Effect of Non-Metallic Inclusions on the Graphite Size of Gray Cast Iron". *J. Iron & Steel Inst.*, Vol. 134, 1936, p. 327P.
[17] U. S. Patent 1,636,657, July, 1927. Also "Effect of Titanium on Cast Iron". E. Piwowarsky. *Stahl u. Eisen*, Vol. 43, 1923, p. 1491, and *Iron Age*, Vol. 117, 1926, p. 1340.
[18] G. F. Comstock. "Results of Comparative Tests of Titanium Treated and Other Alloy Cast Irons". *Trans. Am. Foundrymen's Assoc.*, Vol. 41, 1933, p. 278.
[19] "Titanium-Vanadium Irons". Vanadium Steels and Irons. Vanadium Corporation of America, 1937, p. 175.
[20] G. F. Comstock & E. R. Starkweather. "Comparative Effect of Late Additions of Titanium and Silicon to Gray Cast Iron". *Trans. Am. Foundrymen's Assoc.*, Vol. 46, 1938 (Preprint 38-15).